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Effect of different personal protective equipment on sound discrimination in children using unilateral cochlear implants during the COVID-19 pandemic

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Abstract

Objectives The COVID-19 pandemic obliged people to wear personal protective equipment (PPEs), which can harm verbal communication and speech intelligibility. The first aim was to study the impact of wearing PPEs on the voice and speech parameters of phoniatricians during therapy sessions. The second aim was to study the effect of phoniatricians wearing these PPEs on auditory discrimination of the Ling's six sounds in children using unilateral cochlear implants.

Methods The study was a case–control one, done in the phoniatrics outpatient clinics at Beni-Suef University and Cairo University hospitals. Four phoniatricians participated in this study, and the Dr. Speech software analyzed their speech and voice parameters during utterance of the Ling's six sounds. Each phoniatrician uttered each Ling sound individually four times to assess fundamental frequency and intensity: first time without wearing any mask, second time while wearing a surgical mask, third time while wearing a face shield, and fourth time while wearing an N95 mask. The study also included forty patients using unilateral cochlear implants (group A) and forty children with normal peripheral hearing (group B). The phoniatricians again uttered the Ling's six sounds to assess auditory discrimination in both groups. This subjective auditory discrimination was also tested in both groups four times: first time without wearing any mask, second time while wearing a surgical mask, third time while wearing a face shield, and fourth time while wearing an N95 mask.

Results and conclusion The intensity of Ling's six sounds was significantly lowest in the face shield. Regardless of the PPE type, patients with unilateral cochlear implants showed less consonant discrimination of (mm) sound. Surgical masks and N95 provided the best acoustic performance, while face shields had the worst.

Keywords Personal protective equipment, Cochlear implants, Auditory discrimination, Face shield, N95 mask

Background

In general settings like doctor's offices, schools, and other areas of significant community-based transmission, the US Centers for Disease Control and Prevention (CDC) advised healthcare providers and the public to wear personal protective equipment (PPE) and follow social distancing guidelines during the COVID-19 pandemic. Under COVID-19, people will unavoidably wear

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protective equipment (PPE) when communicating on a daily basis. Different PPE have different compositions and ways of fitting on the wearer's face, so the kind of mask used can affect speech and sound perception differently [1].

When an automatic recognition system is used, a number of internal and external factors lead to undesired unpredictability in the voice signal. Human variables that affect speech production, such as speaking rate, emotion, and vocal effort, are referred to as intrinsic variability. The method by which an acoustic speech signal is received by a human listener or a recognition system is referred to as extrinsic variability. The problems that lead to a natural speech signal changing after it is generated are known as extrinsic factors impacting a recognition system. On the other hand, intrinsic factors refer to a group of influences that cause fluctuations in the realization of an acoustic event during the generation phase [2].

Studies have shown that face masks dampen speech acoustic signals and degrade the effect of verbal communication, which are two critical aspects of message intelligibility. PPE can result in detrimental effects on oral communication and speech intelligibility by occluding important visual cues from the mouth and lip gestures, interfering with natural articulatory movements, and altering speech acoustic features [3].

Corey et al. [4] assessed the effects of various PPE on sound waves. No matter what kind of PPE the talker was wearing, they discovered that sound frequencies higher than four kHz were most dampened. While transparent masks and shields provided the best acoustic attenuation, disposable paper masks provided the best acoustic performance.

Magee et al. [4, 5] assessed the effects of face masks on speech perception and acoustic signals at the word and sentence levels. In line with the findings of Corey et al., Magee and associates observed that three forms of personal protective equipment (PPE) suppressed higher frequencies of acoustic waves in a manner that varied depending on the type of face mask used (i.e., surgical, cloth, N95).

Surgical masks and N95 respirators can reduce higher-frequency sounds between three and 12 dB, according to recent acoustic studies done by Atcherson et al.; however, listening tests using audio-only recordings made with medical masks have not shown significant effects on speech intelligibility [6].

Most masks had little effect below 1 kHz but attenuated higher frequencies to varying degrees. Goldin et al. discovered that the KN95 respirator and surgical mask exhibited peak attenuation of about four dB using a head-and-torso simulator. By roughly six dB, the N95 respirator lowered high frequencies [3].

Truong et al. [7] measured the word recognition rate in an audiovisual listening experiment. They contrasted speech comprehension with and without a two-layer fabric face mask. When the face mask was worn, word recognition decreased from 58 to 53%, blamed on the absence of visual signals.

Nguyen et al. [8] measured human voice characteristics using surgical masks, KN95 masks, and no masks. The KN95 mask provided an average of 5.2 dB attenuation in the 1000–8000 Hz range, while the surgical mask provided an average of 2 dB. No effect was reported below 1000 Hz.

Phoniatrics clinics are essential, as language rehabilitation sessions need direct contact with children at high risk of COVID-19 transmission. Also, any minor changes in the speech signals may affect their auditory perception, especially in children using cochlear implants.

In auditory rehabilitation, the Ling's six-sound test is one of the most popular methods for swiftly determining a patient's ability to hear speech sounds [9]. The Ling's six sounds are widely employed to evaluate the performance of an amplifier (hearing aid) or a cochlear implant. These sounds were chosen because they cover the full spectrum of voice frequencies, from low to high [10]. It is a simple-to-use instrument to assess how well hearing with a cochlear implant and hearing aids works for kids or adults. The assessment is a behavioral listening test that looks for changes in a child's hearing ability using straightforward spoken sounds. The test should be conducted on every school day, every treatment session, and whenever you feel a child's hearing may need improvement [11]. These sounds cover noises with frequencies between 250 and 4000 Hz. The sounds "ah," "ee," "oo," and "mm" characterize speech frequencies up to 1000 Hz; "sh" depicts speech frequencies at 2000 Hz, and "s" describes speech frequencies at 4000 Hz. These sounds, which span speech's low, mid, and high frequencies, must be heard to understand spoken language [12]. The Ling's six sound test has the disadvantage of being an un-calibrated, informal assessment. Furthermore, there is no normative data on the levels at which a person with normal hearing is expected to hear each sound.

This work included an objective assessment and a subjective one. The first aim was to study the impact of wearing PPE on the voice and speech parameters of phoniatricians during therapy sessions. The second aim was to study the effect of phoniatricians' wearing these PPE on auditory discrimination in children using unilateral cochlear implants.

Methods

This case control study was conducted as collaboration between the phoniatrics outpatient clinics in Beni-Suef

University and Cairo University hospitals. All parents consented to their children's participation in the current study. Children were assessed from October 2021 to May 2023; the study had the approval of the Ethics Committee of Beni-surf University, protocol no. FMBSUREC/10102021/Shawky.

The first aim was to study the impact of wearing PPE on the voice and speech parameters of phoniatricians during therapy sessions. The second aim was to study the effect of phoniatricians wearing these PPE on auditory discrimination of the Ling's six sounds in children using unilateral cochlear implants.

1- Four phoniatricians shared in this study using different PPE, and Dr. Speech software assessed their speech and voice parameters like fundamental frequency and intensity (www.drspeech.com)

1. 40 children using unilateral cochlear implants (group A) and 40 children with normal peripheral hearing as a control group (group B) were included in this study.
2. The Ling's six sound test was used in this study to assess the discrimination of low, mid, and high frequencies in both groups.

Study design

A- Each phoniatrician sat in a sound-treated room in front of the computer containing Dr. Speech software at 20 cm from the microphone connected to the computer. The software was calibrated each time before the assessment, and the phoniatricians' voice quality was assessed every time to ensure that their voice analysis criteria were within the normal range.

Dr. Speech software was used to assess the fundamental frequency and intensity of each Ling sound in one setting, and each phoniatrician recorded each Ling sound four times. First time: without wearing any mask; second time: while wearing a surgical mask; third time: wearing a face shield; and forth time: while wearing an N95 mask, so there were 24 results for fundamental frequency and 24 results for intensity for each phoniatrician.

B- Also, auditory discrimination of the Ling's six sounds by children in group A and group B was done as a second step. The assessments were done four times: first time, the phoniatrcian was not wearing any mask; second time, the phoniatrcian was wearing a surgical mask; third time, the phoniatrcian was wearing a face shield; and fourth time, the phoniatrcian was wearing a N95 mask.

The distance between the phoniatrcian and child was less than 1 m, and the auditory discrimination was done from behind for all children.

It was challenging to ask one phoniatrician to assess both groups, so four phoniatricians were included, and each one randomly selected ten children from each group to assess their auditory discrimination.

Their voice quality was assessed to overcome the difference between the four phoniatricians, and their voice criteria were within the normal range.

Inclusion criteria

1) The participating phoniatricians were familiar with the Dr. Speech software.
2) These phoniatricians were experienced in rehabilitating children using unilateral cochlear implants.
3) Group A included children who were implanted for more than 1 year before the onset of the study with an aided threshold of 20–30 dB HL and receiving regular rehabilitation sessions; these children are using only one cochlear implant, as Egyptian insurance covers only one cochlear implant. Also, these children were not using contralateral hearing aids.
4) Group B included children with normal peripheral hearing and typical language development.

Exclusion criteria

1) Any dysphonic attack of the four Phoniatricians.
2) Children using cochlear implants have other disabilities: ADHD, autism, brain damage, and mental retardation.

The results were tabulated and statistically analyzed using the Statistical Program for Social Science (SPSS) version 24.

Results

This study included four phoniatricians and eighty children; these children were divided into two groups: group A included 40 patients using unilateral cochlear implants, and group B included 40 children with normal peripheral hearing. There was no significant difference between the studied groups regarding demographic characteristics. All children in both groups were able to discriminate (ah), (ee), (oo), (s), and (sh) in the four different situations: without any PPE, with surgical mask, with face shield, and with N95. There was a significant difference in

Table 1 Auditory discrimination of the six Ling sounds

Six ling sound	PPE	Study (*n* = 40)	Control (*n* = 40)	^ *p* -value (groups)
Vowel (ah)	Without PPE	40 (100.0%)	40 (100.0%)	NA
	Surgical mask	40 (100.0%)	40 (100.0%)	NA
	Face shield	40 (100.0%)	40 (100.0%)	NA
	N95	40 (100.0%)	40 (100.0%)	NA
Vowel (ee)	Without PPE	40 (100.0%)	40 (100.0%)	NA
	Surgical mask	40 (100.0%)	40 (100.0%)	NA
	Face shield	40 (100.0%)	40 (100.0%)	NA
	N95	40 (100.0%)	40 (100.0%)	NA
Vowel (oo)	Without PPE	40 (100.0%)	40 (100.0%)	NA
	Surgical mask	40 (100.0%)	40 (100.0%)	NA
	Face shield	40 (100.0%)	40 (100.0%)	NA
	N95	40 (100.0%)	40 (100.0%)	NA
Consonant (s)	Without PPE	40 (100.0%)	40 (100.0%)	NA
	Surgical mask	40 (100.0%)	40 (100.0%)	NA
	Face shield	40 (100.0%)	40 (100.0%)	NA
	N95	40 (100.0%)	40 (100.0%)	NA
Consonant (sh)	Without PPE	40 (100.0%)	40 (100.0%)	NA
	Surgical mask	40 (100.0%)	40 (100.0%)	NA
	Face shield	40 (100.0%)	40 (100.0%)	NA
	N95	40 (100.0%)	40 (100.0%)	NA
Consonant (mm)	Without PPE	40 (100.0%)	40 (100.0%)	NA
	Surgical mask	2 (5.0%)	40 (100.0%)	# < 0.001*
	Face shield	6 (15.0%)	40 (100.0%)	# < 0.001 *
	N95	2 (5.0%)	40 (100.0%)	# < 0.001*
	# *p* -value (PPE)	§0.614	NA	# < 0.001*

^Chi square test

[#] Fisher's exact test

[*] Significant

the discrimination of the (mm) sound between the two groups, with no significant difference between different (PPE) among group A (Table 1, Fig. 1).

Table 2 shows no significant difference between different PPE regarding the frequency of the three vowels: (aa), (ee), and (oo). At the same time, there is a substantial difference in the intensity between the various PPE which was significantly lowest with the face shield in the three vowels.

Table 3 shows a significant difference between various PPE in the intensity of (s), (sh), and (mm) sounds, which was significantly lowest with the face shield. While the frequencies of the (s) and (sh) sounds were out of the range, there was no significant difference between PPE regarding the frequency of (mm).

Discussion

During the first wave of the COVID-19 pandemic, all rehabilitation sessions were stopped for fear of its transmission through droplet infection. After a while, rehabilitation sessions were restarted, but wearing PPE was very important. Hence, a new question arose regarding the effect of these PPE on rehabilitation, especially during sessions with children using cochlear implants. Wearing masks can even be a challenge for people with normal hearing; these masks are expected to have more impact on communication for people with hearing loss, as face masks muffle speech and make communication more difficult.

The Ling's six sound test was used to assess low, mid, and high-frequency sound discrimination as it is a reliable subjective assessment. Also, Dr. Speech software was used as it is a powerful objective program for analyzing some voice and speech parameters like intensity and

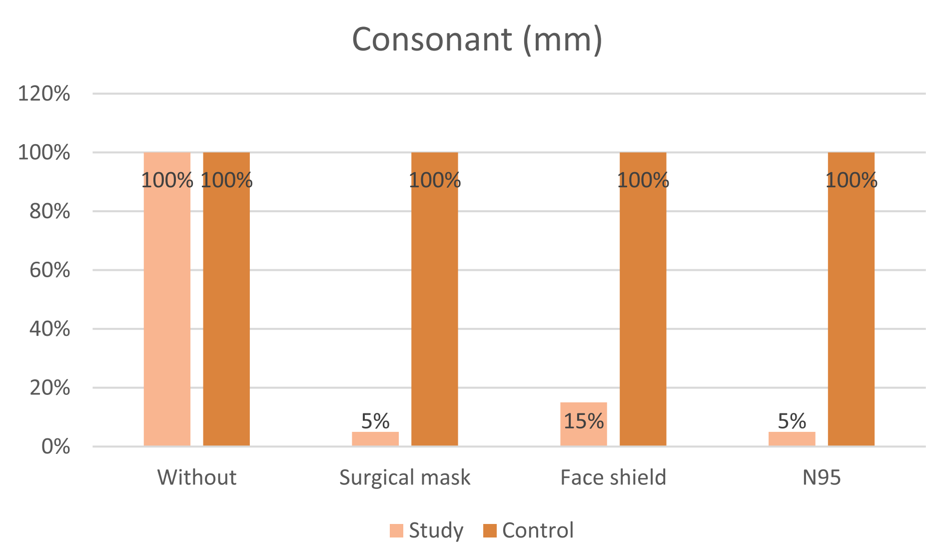

Fig. 1 Consonant (mm) discrimination among the groups

Table 2 The three vowels uttered by the four phoniatricians

	Parameter	Phoniatricians & PPE	Mean ± SD	Range	^ *p*-value
Vowel (ah)	Frequency	Without PPE	197.6 ± 63.9	114.3–276.3	0.998
		Surgical mask	199.1 ± 56.1	117.3–268.1	
		Face shield	200.8 ± 51.5	121.4–262.3	
		N95	201.8 ± 55.1	119.6–270.2	
	Intensity	Without PPE	56.7 ± 5.7	46.1–62.0	0.005*
		Surgical mask	54.8 ± 4.7	45.2–59.8	
		Face shield	48.5 ± 5.7	41.5–54.5	
		N95	53.5 ± 3.1	48.7–60.4	
Vowel (ee)	Frequency	Without PPE	217.9 ± 61.7	136.5–295.0	0.640
		Surgical mask	219.1 ± 45.3	154.2–275.0	
		Face shield	241.5 ± 48.7	170.5–291.1	
		N95	232.2 ± 26.3	183.3–263.2	
	Intensity	Without PPE	55.5 ± 7.1	44.1–66.6	0.049*
		Surgical mask	50.7 ± 8.0	40.0–62.3	
		Face shield	47.0 ± 4.8	38.9–53.2	
		N95	53.0 ± 6.7	42.7–63.1	
Vowel (oo)	Frequency	Without PPE	223.2 ± 63.1	150.3–303.0	0.941
		Surgical mask	224.1 ± 58.8	159.6–303.0	
		Face shield	233.9 ± 21.3	200.2–259.3	
		N95	232.2 ± 36.3	190.9–282.5	
	Intensity	Without PPE	57.7 ± 4.9	48.5–65.4	0.001*
		Surgical mask	54.0 ± 3.9	46.6–59.2	
		Face shield	47.0 ± 6.7	38.7–56.0	
		N95	51.0 ± 6.3	42.9–59.6	

^ANOVA test

* Significant

fundamental frequencies. The two groups were matched regarding demographic characteristics (age and sex). The mean duration of the implant in group A children was 3.3 ± 1.3 years. Also, the voice criteria of four phoniatricians were within normal during every assessment session.

Trecca et al. [13] studied the early findings on the effect of medical staff wearing PPE on the perceived challenges faced by 59 persons with hearing loss throughout their hospital stay. They stated that 13.6% of subjects did not have difficulties, and 86.4% complained of minor to severe issues. Interestingly, the main concern about face masks was the sound attenuation for 26 (44.1%) subjects and the impossibility of lip reading for 33 (55.9%).

In this study, the results showed that both groups were able to discriminate five Ling sounds (ah), (ee), (oo), (s), and (sh) in the four different situations: without a surgical mask, with a surgical mask, face shield, and N95. The consonant (mm) was significantly less discriminated among the study group than the control group, with no significant difference between different PPE, as shown in Fig. 1.

This is explained by that PPE are known to distort the low frequency sounds as shown by other studies; this is in accordance with what was found in this study. The population under study showed less discrimination to (mm) sound when the stimulus was presented using the PPE. Another explanation is that most CI users are better at discriminating high frequencies than low frequencies.

Also, Truong et al. [14] discovered that conversational words in silence caused worse cued recall when a talker wore a mask. The kind of mask and where the microphone is placed may be partially responsible for this variation; talkers wore surgical masks, and a lapel mic placed close to the talker's mouth enhanced the voice signal (though still outside of the mask). In this investigation, talkers donned cloth masks while a stationary microphone recorded the talkers' signals.

In this study, during the phoniatricians' utterance of the six Ling sounds in front of the microphone using the Dr. Speech software, frequencies of (s) and (sh) were out of range. The frequency of other Ling sounds showed no significant difference between the two groups as shown in Tables 2 and 3. In this study, the intensity of the six

Table 3 The three consonants uttered by the four phoniatricians

	Parameter	PPE	Mean ± SD	Range	^ *p*-value
Consonant (s)	Frequency	Without PPE	0.0 ± 0.0	0.0–0.0	0.999
		Surgical mask	0.0 ± 0.0	0.0–0.0	
		Face shield	0.0 ± 0.0	0.0–0.0	
		N95	0.0 ± 0.0	0.0–0.0	
	Intensity	Without PPE	56.5 ± 2.5	53.2–61.6	< 0.001*
		Surgical mask	48.0 ± 4.9	39.0–53.3	
		Face shield	42.1 ± 7.0	34.2–57.5	
		N95	45.4 ± 3.8	39.7–52.6	
Consonant (sh)	Frequency	Without PPE	0.0 ± 0.0	0.0–0.0	0.999
		Surgical mask	0.0 ± 0.0	0.0–0.0	
		Face shield	0.0 ± 0.0	0.0–0.0	
		N95	0.0 ± 0.0	0.0–0.0	
	Intensity	Without PPE	56.7 ± 6.5	47.6–65.2	0.037*
		Surgical mask	56.7 ± 7.0	48.0–66.6	
		Face shield	48.7 ± 7.3	38.3–58.4	
		N95	52.9 ± 6.3	46.3–62.8	
Consonant (mm)	Frequency	Without PPE	220.4 ± 41.5	190.6–297.0	0.740
		Surgical mask	237.3 ± 45.3	199.7–303.0	
		Face shield	232.7 ± 24.0	204.6–260.1	
		N95	230.3 ± 22.8	209.6–263.1	
	Intensity	Without PPE	51.4 ± 6.6	41.2–59.1	0.215*
		Surgical mask	49.6 ± 4.4	42.3–54.3	
		Face shield	46.4 ± 6.5	38.9–55.9	
		N95	51.0 ± 5.2	42.5–56.1	

^ANOVA test

* Significant

Ling sounds (aa), (oo), (ee), (s), (mm), and (sh) was significantly different using the PPE; the lowest was for the face shield, as shown in Tables 2 and 3. This can be explained by the fact that the phoniatricians may have unintentionally increased their voice loudness while using PPE, so the intensity of the six Ling sounds mostly has stayed the same.

Previous research studied the acoustic effects of twelve different masks and concluded that all types of masks attenuated sounds above 1000 Hz. The worst acoustic performance, however, was shown by transparent masks and face shields, which increased the volume of sound below 1 kHz and significantly attenuated sound above 1 kHz. Such a result is different from the results of the current study. This difference may be due to the personal variation in vocal loudness between phoniatricians in this study or by the small number, which is a factor leading to bias [4].

Also, Nguyen et al. [8] compared speech measurement using the records of 16 persons, both with and without a KN95 or medical mask. The researchers examined the first band to the second energy ratio, the HNR for the two bands, voice intensity, and smooth cepstral peak prominence (CPPS) of the two bands using average spectral levels for the two bands below 1 kHz and between 1 and 8 kHz. At the 1/8 kHz band, there is an evident average spectral level attenuation; however, at the less than 1 kHz band, there was hardly any attenuation. Vowel average spectral levels for face-masked speech barely changed. Speech with a face mask has a higher HNR than speech without a face mask. Mask use had little impact on CPPS or voice intensity.

Atcherson et al. [15] conducted a study to assess the speech perception abilities of listeners with normal hearing, moderate, and severe-to-profound hearing loss using a traditional paper surgical face mask with a transparent ("see-through") prototype surgical face mask. The spectral analysis of the voice stimuli with and without the masks revealed a sizable difference. They discovered that while people with good hearing did not need visual cues, hard-of-hearing people performed better using a transparent mask.

In agreement with the study's result, Mendel et al. [16] stated that the spectral analysis of speech stimuli with and without surgical masks showed a substantial difference. While wearing a surgical mask, they reported no difference in speech comprehension between people with normal hearing and hearing loss.

A previous study assessed 42 patients with hearing loss. Each participant had a cochlear implant or one or more hearing aids or cochlear implants. The face shield's acoustic performance was worse when compared to that of the surgical mask [17].

Additionally, Nada et al. [18] found that, in comparison to KN95, surgical masks had less of an impact on speech discrimination across all groups. Individuals experiencing high-frequency hearing loss are particularly vulnerable to the adverse consequences associated with face mask use. Therefore, it is advised to utilize surgical masks rather than KN95, particularly in scenarios where a high level of protection is not required. These results should be taken into account because they will affect communication, particularly in settings like hospitals where individuals need to comprehend teachers and medical professionals extremely effectively.

Conclusion and recommendations

In conclusion, regardless of the PPE type used, patients with unilateral cochlear implants showed less auditory discrimination of consonants (mm). The intensity of six Ling sounds was significantly lower with the face shield. Surgical masks and N95 provide the best acoustic performance, so they can be used during auditory and language training of CI children, while face shields had the worst performance. Larger-scale studies are recommended on the effect of PPE using different voice analysis systems on the speech perception of cochlear implants and hearing aid users.

Limitations

One of the limitations of this study was that the assessment of the frequency (s) and (sh) was not calculated by Dr. Speech software as they were out of range of this software.

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Authors' contributions
Dr. Ayatallah Raouf Sheikhany shared in the Study conception, methodology, and data collection. Also she discussed the results, wrote the paper, contributed to the final manuscript, read and approved the final manuscript. Prof. Dr. Safinaz Nageib Azzab shared in the study conception, and work design. She discussed the results, wrote the paper, contributed to the final manuscript. Finally she read and approved the final manuscript. Dr. Mohamed Ayman Mohamed Shawky shared in acquisition, analysis of data, data collection, and performed the analysis. He interpreted the data, discussed the results, wrote the paper, contributed to the final manuscript, read and approved the final manuscript. Dr. Ahmed Ali Abdelmonem shared in the study conception, acquisition, analysis of data, data collection. He performed the analysis, interpreted the data, discussed the results, and wrote the paper, contributed to the final manuscript. Finally he read and approved the final manuscript.

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Availability of data and materials
The data that support the findings of this study are available on request from the corresponding author.

Declarations

Ethics approval and consent to participate
The study had the approval of the Ethics Committee of Beni-suef University, protocol no. (FMBSUREC/10102021/Shawky).
All parents consented verbally to their children participation in the current study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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