Original Article

Effect of the sound of the mother's heartbeat combined with white noise on heart rate, weight, and sleep in premature infants: a retrospective comparative cohort study

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Background: The neonate intensive care unit (NICU) is a high-stress environment can affect the hormone secretion, cardiopulmonary function, sleep/wake cycle, alertness, temperature regulation, and intellectual development of premature infants. It is not conducive to their recovery, growth, and development. The sound of the mother's heartbeat and white noise can stabilize the heart rate and respiration of premature infants and alleviate pain. This study aims to analyze the effects of the sound of the mother's heartbeat combined with white noise on the heart rate, weight, and sleep status of premature infants in the NICU.

Methods: We retrospectively analyzed 121 premature infants admitted to the Newborn Department of Suzhou Kowloon Hospital from January 2019 to December 2021. The infants were divided into an intervention group (those given the mother's heartbeat sound combined with white noise) and a control group (routine treatment and nursing); the heart rate, sleep state, weight and weight gain rate of the two groups were compared before and after the intervention.

Results: The heart rate and behavioral status scores of the intervention group during the intervention (10, 20 min) and 1 min after the intervention were significantly lower than 1 min before the intervention ($P<0.05$). The intervention group's weight was significantly higher than the control group's on the 14th day after intervention ($P<0.05$), and the rate of weight gain was faster than that of the control group ($P<0.05$). The average daily milk intake of the intervention group in the first and second weeks was higher than that in the control group ($P<0.05$). Multiple stepwise regression analysis showed that the rate of weight gain in the intervention group was higher than that in the control group ($P<0.05$).

Conclusions: The combination of the auditory stimulation of the mother's heartbeat and white noise for premature infants in NICU can effectively reduce the heart rate of premature infants, stabilize their mood, promote their sleep, increase the amount of milk consumption during hospitalization, increase the rate of weight gain, and promote their physical development.

Keywords: Premature infant; mother's heartbeat; white noise; heart rate; weight

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Introduction

According to the latest report of the World Health Organization (WHO), about 15 million premature babies are born worldwide every year, and the incidence of premature births is 5–18% and rising (1). The number of premature births in China ranks second in the world. The increasingly serious environmental pollution, the commencement of the three-child policy, the increase in older pregnant women, and the impact of the novel coronavirus on pregnant women have caused the incidence of premature births in China to increase each year (2). Previous research (3) has found that during the growth and development of premature infants, they often face a high risk of respiratory insufficiency, asphyxia, jaundice, and infection in the short term, while in the long term, they often face problems of neurodevelopmental dysfunction, learning disabilities, high rehospitalization rates, and growth and feeding difficulties. The treatment and care of premature infants are mainly carried out in the neonatal intensive care unit (NICU), but the noisy atmosphere of instrument alarms and equipment, the voices of staff, and noise from other procedures create an enduring high-stress environment (4) for premature infants that can affect their hormone secretion (such as melatonin, cortisol, and growth hormone), cardiopulmonary function (increased heart rate, decreased blood oxygen saturation, and increased blood pressure), sleep/wake cycle, alertness, temperature regulation, and intellectual development (5). None of these are conducive to the recovery and growth of premature infants. Early intervention in NICU is helpful for the prognosis and growth of preterm infants (6). Although drug intervention can sedate premature infants, reduce restlessness, and increase sleep time, drugs often have side effects, such as dependence, withdrawal symptoms, and respiratory depression (7), which are unsuitable for long-term use. Therefore, exploring non-drug interventions for premature infants in NICU is worthwhile. A good environment that simulates the uterus, such as the appropriate temperature and humidity in the incubator, swaddling the baby, and a light/dark cycle (8), can help premature infants transition from the mother's internal environment to the external environment (9). A study has shown that early auditory stimulation intervention for NICU preterm infants can regulate their digestive, nervous, and circulatory systems, stabilize their physiological state, and promote growth and development (10). The sound of the mother's heartbeat has been shown to stabilize the heart rate and respiration of premature infants, reduce pain, and promote weight gain (11). White noise has also been shown to alleviate pain, reduce the heart rate, and maintain high oxygen saturation in premature infants (9,12). The auditory stimulation involves recording the sound of the mother's heartbeat combined with white noise. It is then played in the incubator to simulate the sound of the environment in the womb (9). Recent research at home and abroad has mainly focused on the sound of the mother's heartbeat or white noise on the experience of pain and weight of preterm infants. This study integrated the sound of the mother's heartbeat with white noise to produce a comforting auditory stimulation similar to that of the womb and aimed to study its impact on the heart rate, weight, and sleep of premature infants. We present the following article in accordance with the STROBE reporting checklist (available at https://apm.amegroups.com/article/view/10.21037/apm-22-1269/rc).

Highlight box

Key findings

- The combination of the auditory stimulation of the mother's heartbeat and white noise for premature infants in NICU can reduce the heart rate of premature infants, stabilize their mood, promote their sleep, increase the amount of milk consumption, and promote their physical development.

What is known and what is new?

- The sound of the mother's heartbeat can stabilize heart rate and respiration of premature infants, reduce pain, and promote weight gain.
- This study found that the synthesis of the sound of mother's heartbeat with white noise can effectively stabilize infants' mood, promote their sleep.

What is the implication, and what should change now?

- We can record heart sounds for mothers, so that they can participate in the care of premature infants in a unique way, which can stabilize the mood of infants, and reduce the discomfort that mothers cannot participate in the care of children.

Methods

Research participants

Preterm infants admitted to the Newborn Department of Suzhou Kowloon Hospital from January 2019 to December 2021 were retrospectively analyzed (*Figure 1*).

The inclusion criteria for premature infants were as follows: (I) the vital signs were stable within 24 h of birth; (II) gestational age was ≥27 and <37 weeks; (III) the Apgar score

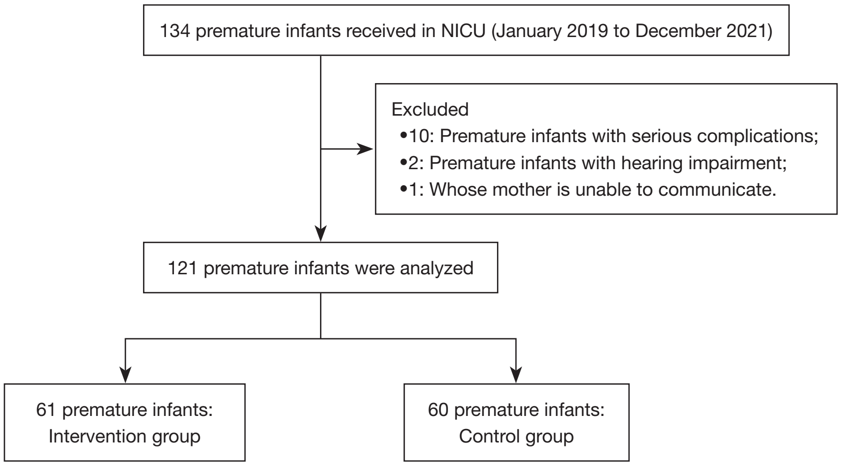

Figure 1 Flowchart of enrollment for premature infants. NICU, neonatal intensive care unit.

was ≥7 at the 1st, 5th and 10th minute after birth; (IV) normal hearing.

Premature infants were excluded if they had any of the following: (I) loss of consciousness; (II) hearing impairment; (III) serious complications, such as intracranial hemorrhage, severe asphyxia, severe infection, mechanical ventilation, NEC, or serious heart disease.

Mothers were included if they showed (I) good cooperation and (II) stable condition and mood. Mothers who could not communicate, had a history of mental illness, or had serious postpartum complications were excluded. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and was approved by the Ethics Committee of Suzhou Kowloon Hospital, Shanghai Jiao Tong University School of Medicine (No. 20220981-33). All parents gave informed consent to participate in this study.

Heartbeat sound collection and processing

Within 48 h of the birth of the premature infant, the researchers consulted with the mother to determine a convenient time to record her heartbeat. (I) The recording of the mother's heartbeat was conducted when the mother's mood was stable, and the surrounding environment was quiet. A Doppler fetal heart monitor was used to detect the mother's heartbeat. After ensuring the heart rate was regular and stable, a recording pen was used to record the mother's heartbeat for 30 min. (II) The white noise (the sound of light rain) was downloaded from the white noise application of a smartphone or computer (https://www.youtube.com). (III) The recorded heartbeat was mixed with the white noise.

Volume control requirements

A study has shown that the fetus responds to sound at 24 weeks and develops auditory ability at 32 weeks (13). The fetus can hear the mother's heartbeat, voice, and the sound of the surrounding environment in the uterus. In this study, we had strict criteria for the volume and duration of the playback because if the volume exceeds 70 dB, it may cause hearing damage, apnea, increased blood pressure and heart rate, decreased oxygen saturation, sleep difficulties, and other adverse effects for premature infants (14). Therefore, in this study, we specified a volume between 35 and 45 dB for the intervention, with the duration of play lasting 30 min once a day for 14 days.

Intervention methods

Control group

Routine treatment and nursing were given, including the following: (I) preterm infants were placed in a light-shielded and closed incubator immediately after entering NICU and swaddled to simulate the intrauterine environment as much as possible; (II) nursing and monitoring of the infant's body temperature, respiration, feeding, skin, and infection were conducted; (III) the medical staff were reminded to lower their voice, conduct procedures in a centralized manner, and reduce the noise of instrument alarms; (IV) during the study, any treatment for illness was conducted as usual.

Intervention group

In addition to the routine treatment and nursing administered to the control group, the following operations were performed: (I) the quiet periods of 12:30–13:30 and 18:30–19:30 were selected to play the synthesized mother's heart sounds for 30 min for preterm infants, and the intervention lasted for 14 days. The procedure was as follows: the synthesized heartbeat with white noise was recorded on a player wrapped in a disposable treatment towel. The volume was measured with a decibel meter to ensure that it was between 35 and 45 dB, then the player was placed above the child head, and a camera was used to observe the child's facial expression. The child had been fed at 12:00 and 18:00 and was in a quiet and awake state. The surrounding environment was quiet.

Evaluation indicators

Heart rate index: in this study, a portable multi-parameter monitor was used to record the heart rate of premature infants 1 min before the intervention, during the intervention (10^{th} and 20^{th} min), and 1 min after the intervention. Because a premature infant's heart rate is generally unstable, it was continuously observed for 1 min. The value was recorded every 10 s, an average value of 6 times in 1 min.

Body weight index: (I) the weight of premature infants at birth and 7 and 14 days after the intervention was recorded. (II) Growth velocity (GV) = [1,000× Ln (Wn/W1)/Dn − D1], where GV = growth velocity, W = weight in grams, D = day, 1 = beginning of the time interval, and n = end of the time interval in days. (III) The formula for calculating the average daily milk consumption (where Ni is the daily milk consumption) was as follows: the average daily milk consumption in the first week (ML) = (N1 + N2 +... + N7) / 7; the average daily milk consumption in the second week (ML) = (N8 + N9 +... + N14) / 7.

Sleep index

The sleep and wake cycles of the newborns were recorded. The Anderson Behavioral State Scale (ABSS) was used to evaluate the sleep status of preterm infants 1 min before, during (10^{th} and 20^{th} min), and 1 min after the intervention. Because the same behavior state of premature infants is only maintained for a short time, it is necessary to continuously observe for 1 min and select the most significant behavior state within that min for scoring and recording. This scale was developed by Anderson *et al.* in 1990 (15). It divides neonatal behavior states into 12 types and assigns points from 12–1 for each behavior in the following sequence: hard crying, crying, fussing, very active, active, quiet awake, alert inactive, drowsy, very active sleep, active sleep, irregular quiet sleep, regular quiet sleep. The higher the score, the worse the behavior state. The scale has good content validity, aggregation validity, and criterion validity, and the inter-rater reliability is ≥95%. It has been widely used to measure the behavioral status of premature infants (16).

Statistical analysis

EpiData 3.1 software was used to establish the database, and two researchers entered and proofread the data. The Statistical Program of Social Science software version 24.0 (SPSS Inc., Chicago, IL, USA) was used for the statistical analysis. The measurement data were tested for normal distribution, expressed by means ± standard deviations, and compared between groups by *t*-test or non-parametric test; count data were expressed by n (%), and the chi-square test was used for comparisons between groups; multiple linear regression was used to correct for confounding factors. A two-sided test with a P value <0.05 was considered statistically significant.

Results

Baseline data

There were 61 cases in the intervention group and 60 in the control group. There was no statistical difference between the two groups in terms of gestational age, birth weight, sex, Apgar score at 1, 5, and 10 min, or the mothers' general data (all P>0.05) (*Table 1*).

Comparison of heart rate between the two groups of premature infants

There was no significant difference in heart rate between the two groups 1 min before the intervention (P>0.05). The heart rate of the intervention group was lower than that of the control group during the intervention (10, 20 min) and 1 min after the intervention (P<0.05). There was no significant difference in heart rate between the control group before, during, and after the intervention (P>0.05). The heart rate of the intervention group during the intervention (10, 20 min) and 1 min after the intervention was significantly lower than 1 min before the intervention (P<0.05) (*Table 2* and *Figure 2*).

Table 1 Baseline data of the two groups ($\bar{x} \pm s$)

Variables	Intervention group (n=61)	Control group (n=60)	t/χ^2	P value
Gender (male/female)	34/27	42/18	2.634	0.105
Gestational age (day)	229.70±7.87	231.71±7.34	1.453	0.149
Birth weight (g)	1,702.52±105.39	1,669.91±105.53	1.701	0.092
Apgar score at 1 min	7.90±0.85	8.07±0.92	1.026	0.307
Apgar score at 5 min	9.0±0.41	8.97±0.32	0.501	0.617
Apgar score at 10 min	9.66±0.48	9.58±0.50	0.816	0.416
Maternal age (years)	32.36±3.91	32.52±4.18	0.212	0.832
Perinatal complications (yes/no)	16/45	17/43	0.067	0.795
Pregnancy number (1/2/3/>3)	31/14/12/4	29/15/6/10	4.665	0.198
Parity (1/2/3)	46/13/2	44/13/3	0.236	0.889
Mode of delivery (vaginal delivery/cesarean section)	18/43	15/45	0.310	0.578
Twin or multiple (yes/no)	16/45	17/43	0.067	0.795
Mother's education (Junior college or below/Bachelor's degree or above)	37/24	38/22	0.092	0.762
Perinatal complications (yes/no)	16/45	17/43	0.067	0.795

Table 2 Comparison of heart rate between the two premature infant groups ($\bar{x} \pm s$)

Time point	Heart rate, times/min		t	P value
	Intervention group (n=61)	Control group (n=60)		
1 min before intervention	149.21±8.72	148.68±8.69	0.335	0.738
Intervention (10th minute)	139.33±9.55*	147.63±8.74	4.989	0.000
Intervention (20th minute)	130.36±9.3*	148.3±9.16	10.689	0.000
1 min after intervention	128.57±6.77*	149.37±9.11	14.266	0.000

Data are shown as $\bar{x}$ ± s. Compared with before intervention, *P<0.05.

Comparison of behavior status scores between the two groups of premature infants

There was no significant difference in behavioral status scores between the two groups 1 min before intervention (P>0.05). The behavioral status scores of the intervention group were lower than those of the control group during the intervention (10, 20 min) and 1 min after the intervention (P<0.05). There was no significant difference in behavioral status scores in the control group before, during, and after the intervention (P>0.05). The behavioral status scores of the intervention group during the intervention (10, 20 min) and 1 min after the intervention were significantly lower than 1 min before the intervention (P<0.05) (*Table 3* and *Figure 3*).

Comparison of body weight development between the two groups of premature infants

There was no statistically significant difference in birth weight between the two groups (P>0.05). The weight of the intervention group was higher than that of the control group on the 7th day of intervention, but the difference was not statistically significant (P=0.052). The weight of the intervention group was significantly higher than that of the control group on the 14th day of intervention (P<0.05), and the rate of weight gain was faster than that of the control group (P<0.05); The average daily milk intake in the first and second weeks was higher in the intervention group than in the control group (P<0.05) (*Table 4*).

General factors affecting the rate of weight gain in premature infants

With grouping, gestational age, birth weight, twin or multiple, average daily milk volume 14 days after interaction as independent variables, and the weight gain rate of premature infants as dependent variables, analyze the data variables that affect the weight gain rate of premature infants in general data questionnaire, statistical analysis showed that group, gestational age, birth weight, twin or multiple, and average daily milk intake 14 days after intervention had a significant impact on the rate of weight gain of premature infants (P<0.05) (*Table 5*).

Correlation analysis between weight gain in premature infants and its influencing factors

Multiple stepwise regression analysis was conducted using the weight gain rate as the dependent variable and significant variables from the univariate analysis as the independent variables. The results showed that there was a positive correlation between weight gain rate and gestational age, birth weight, and group, insofar as the weight gain rate of infants in the intervention group was higher than in the control group (P<0.05) (*Table 6*).

Discussion

From the perspective of physiology and biology, an increased heart rate is a defense state, and a decreased rate is a good adaptive response. The noisy environment formed by the alarms of various machines and the talk and procedures carried out by medical staff in the NICU can increase the heart rate of premature infants, disturb their sleep patterns, and accelerate their energy consumption, which is not conducive to their growth and development (17,18). The mother's voice is the first and most important low-frequency sound heard by newborns. They can recognize their mother's voice at birth (19). Arnon *et al.* (20) found that hearing the mother's heartbeat in the NICU setting can improve the breathing, cardiac function, and feeding of premature infants. In this study, the heart rate of the control group did not change significantly throughout the intervention period, but the heart rate of the intervention

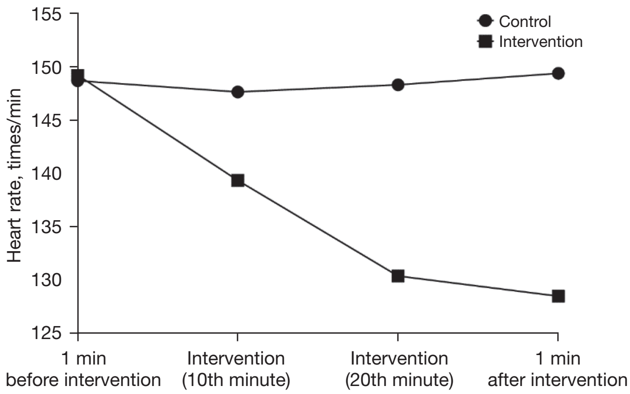

Figure 2 Heart rate line chart.

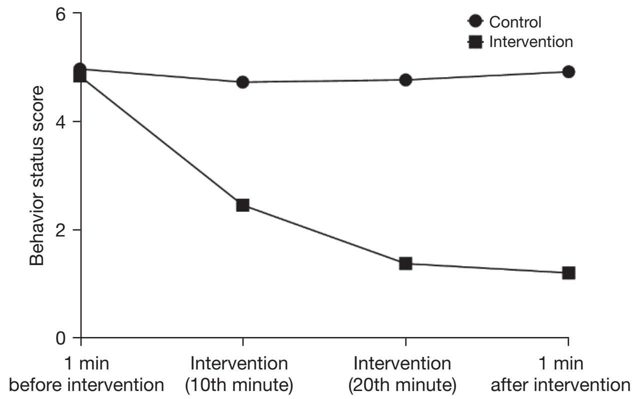

Figure 3 Line chart of the Anderson Behavior Status Score.

Table 3 Comparison of behavioral status scores between the two premature infant groups ($\bar{x} \pm s$)

Time point	Behavior status score		t	P value
	Intervention group (n=61)	Control group (n=60)		
1 min before intervention	4.84±0.61	4.97±0.78	1.026	0.307
Intervention (10^{th} minute)	2.46±0.53*	4.73±0.66	20.837	0.000
Intervention (20^{th} minute)	1.38±0.49*	4.77±0.56	35.368	0.000
1 min after intervention	1.21±0.41*	4.92±0.79	32.476	0.000

Compared with before intervention, *P<0.05.

Table 4 Comparison of body weight gain between the two premature infants' groups ($\bar{x} \pm s$)

Item	Intervention group (n=61)	Control group (n=60)	*t*	P value
Body weight 7 days after intervention (g)	1,800.43±140.99	1,755.32±109.61	1.963	0.052
Body weight 14 days after intervention (g)	1,989.3±91.48	1,800.48±112.5	10.136	0.000
Average daily milk volume 7 days after intervention (mL/d)	81.23±10.74	73.9±14.91	3.107	0.002
Average daily milk volume 14 days after intervention (mL/d)	280.44±20.53	213.82±27.97	14.954	0.000
Weight gain rate (g/kg/d)	12.04±1.8	9.97±1.08	7.649	0.000

Table 5 Single factor analysis of weight gain rate ($\bar{x} \pm s$)

Variables	n	Weight gain rate (g/kg/d)	F	P
Group			58.504	0.000
Intervention group	61	12.04±1.80		
Control group	60	9.97±1.08		
Gestational age (day)			20.801	0.000
208–224	23	9.90±1.13		
225–238	83	10.71±1.28		
239–252	15	12.84±2.52		
Birth weight (g)			7.102	0.001
1,400–1,599	22	10.02±1.66		
1,600–1,799	86	10.88±1.36		
1,800–1,999	13	12.13±2.78		
Twin or multiple			9.873	0.002
Yes	33	10.20±1.25		
No	88	11.31±1.90		
Average daily milk volume 14 days after intervention (mL/d)			9.452	0.000
150–199	22	10.31±1.50		
200–249	37	10.31±1.94		
250–299	51	11.95±1.45		
300–349	11	10.48±1.70		

Table 6 Multiple regression analysis of weight gain rate

Related factor	B	SE	β	*t*	P
Group	2.270	0.398	0.629	5.706	0.000
Gestational age (day)	0.887	0.260	0.273	3.412	0.001
Birth weight (g)	0.750	0.260	0.221	2.886	0.005
Twin or multiple	0.315	0.279	0.078	1.128	0.261
Average daily milk volume 14 days after intervention (mL/d)	0.131	0.231	0.065	0.570	0.570

group decreased significantly. These results indicate that the sound of the mother's heartbeat can effectively stabilize the premature infant's heart rate. The synthesis of the mother's heartbeat with white noise creates a sound similar to that of the mother's intrauterine environment for premature infants, which has the effect of stabilizing their physiological response, thus reducing their heart rate. Additionally, the quiet period of NICU was selected for intervention in this study. Preterm infants were routinely placed in a warm incubator, which blocked the external noise by about 5–10 dB. During the study, the surrounding environment was kept quiet as much as possible to minimize the impact of noise on the heart rate of preterm infants and give full play to the sound stimulation effect of the mother's heartbeat and white noise. Because premature infants' systems are not fully developed, their sleep, growth, and development are often affected by the stimulation of the NICU treatment environment and pain (21). Studies have found that artificial voice intervention can make premature infants remain quiet, reduce crying, and improve sleep conditions (19). Loewy's study (22) simulated the sound of amniotic fluid in the womb and the mother's heartbeat and found that this combination reduced the heart rate, improved the sucking ability, and improved the sleep of premature infants. Our results showed that the sleep state of the control group did not change significantly with the intervention, which may be related to the high noise environment of NICU affecting the sleep state of premature infants. The overall behavioral status score of the preterm infants in the intervention group showed a downward trend. Our results showed that the sound of the mother's heartbeat caused preterm infants to achieve better sleep; the reason for this may be that the sound of the heart beating during the fetal period can be transmitted through the amniotic fluid, creating an auditory stimulus for the fetus (23). When separated from their mother, premature infants lack a sense of security, which manifests as irritability, frequent waking, and crying. When they hear the familiar uterine sound environment, they stabilize physiologically, have an increased sense of security, and demonstrate better sleep and behavior.

Premature infants have a high risk of developmental delay due to insufficient nutrition in the first few weeks after birth. Despite the progress made in neonatal care, risks still exist due to the metabolic and gastrointestinal immaturity, impaired immune systems, and other medical complications of preterm infants. Growth status and rate are important health outcomes for premature infants. The immediate recovery of adequate body weight in preterm infants after birth is crucial for establishing a sustained growth trajectory (24). The results of this study show that, compared with the control group, the intervention group had a faster weight gain and a shorter time to birth-weight recovery. The possible reason is that the intervention soothed the premature infants with the heartbeat and white noise sounds so that they were in a relaxed and comfortable state, which reduced their stress and crying and thus reduced their energy consumption; at the same time, the amount of their milk consumption gradually increased, which promoted their physical development. A study speculated that the soothing sound of the mother's heartbeat leads to an overall reduction of stress, which leads to improvement in the sleep/wake cycle and behavioral status, thus helping infants to save more energy and gain weight (25). The reason may be that premature infants have become familiar with hearing their mother's heartbeat in the womb, and white noise has a positive impact on the newborn's sleep (25). Combining the two can make premature infants feel safe and comfortable, reduce their experience of pain, facilitate the development of their nervous system, and help them tolerate the increase in milk volume, thus promoting weight gain.

Conclusions

Premature infants require treatment in NICU, which involves separation from their mothers. For mothers, premature birth means they can't take care of their children themselves, which may lead to various emotional disorders. In serious cases, it leads to depression, which may affect early parent-child bonding and marital and family relationships (26). For preterm infants, separation from their mothers can induce stress and adversely affect their behavior and nervous system development (27). Recording their heartbeat allows mothers to participate in the care of their preterm infants in a unique way, which not only reduces their anxiety but also strengthens their attachment to their child and alleviates their fear or discomfort of not being able to participate in the care of their child more fully. This study found that the synthesis of the sound of the mother's heartbeat with white noise can effectively reduce the heart rate of premature infants in NICU, stabilize their mood, promote their sleep, increase the amount of milk consumption during hospitalization, improve the rate of weight gain, and promote their physical development. It is worth popularizing and applying in clinical settings.

The main disadvantage of this study is that due to limited time and manpower, the follow-up period to measure weight gain was relatively short, and a more extended follow-up period is recommended in future studies.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://apm.amegroups.com/article/view/10.21037/apm-22-1269/rc

Data Sharing Statement: Available at https://apm.amegroups.com/article/view/10.21037/apm-22-1269/dss

Conflicts of Interest: Both authors have completed the ICMJE uniform disclosure form (available at https://apm.amegroups.com/article/view/10.21037/apm-22-1269/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Ethics Committee of Suzhou Kowloon Hospital, Shanghai Jiao Tong University School of Medicine (No. 20220981-33). Informed consent was obtained from all parents.

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