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Impact of Aquatic Therapy in the NICU on diaphragmatic mobility assessed by ultrasound: clinical trial

Impacto da fisioterapia aquática em UTIN sobre a mobilidade diafragmática avaliada por ultrassonografia cinesiológica: ensaio clínico

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ABSTRACT | INTRODUCTION: Aquatic physiotherapy is a modality of hydrotherapy performed on newborn babies (NB) in the Neonatal Intensive Care Unit (NICU). The effects on pain levels, behavior, and respiratory function are already known; however, little has been said about the effects on diaphragmatic function in the preterm newborn population. **OBJECTIVE:** To evaluate the effect of aquatic physiotherapy on diaphragmatic amplitude using diaphragmatic kinesiologic ultrasound (DKUS) in NBs admitted to a NICU, as well as the safety regarding the clinical stability of the NBs, behavioral state, pain, and respiratory distress. **METHODS:** Cross-sectional before-and-after clinical trial. The NBs participating in the study received a single intervention with aquatic physiotherapy for 10 minutes. An assessment was performed using the USCD before and after the session, and heart and respiratory rates, behavioral state, pain, and respiratory discomfort were recorded. **RESULTS:** Twenty-six NBs participated. There was a significant increase in diaphragmatic amplitude (p= 0.02) and peripheral oxygen saturation (p= 0.05); physiological parameters remained within normal limits, and the intervention did not cause behavioral disorganization, pain, or respiratory discomfort in NBs. **CONCLUSION:** Aquatic physiotherapy promoted an increase in diaphragmatic amplitude, suggesting that this technique can be used as a way to stimulate the contraction of the respiratory muscles in NB, in addition to being a safe technique, as it did not generate clinical instability, behavioral disorganization, pain, or respiratory discomfort to the participants.

KEYWORDS: Hydrotherapy. Aquatic Therapy. Ultrasonography. Diaphragm. Newborn.

RESUMO | INTRODUÇÃO: A fisioterapia aquática é uma modalidade de hidroterapia realizada em recém-nascidos (RN) nas Unidades de Terapia Intensiva Neonatal (UTIN). Os efeitos sobre nível de dor, estado comportamental e função respiratória já são conhecidos, porém pouco se refere aos efeitos sobre a função diafragmática na população recém-nascida a termo prematura. **OBJETIVO:** Avaliar o efeito da fisioterapia aquática sobre a amplitude diafragmática por meio da ultrassonografia cinesiológica diafragmática (USCD) em RNs internados em UTIN, bem como a segurança de sua realização quanto a estabilidade clínica dos RNs, estado comportamental, dor e desconforto respiratório. **MÉTODOS:** Ensaio clínico tipo antes e depois, de caráter transversal. Os RNs participantes do estudo receberam uma única intervenção com fisioterapia aquática durante 10 minutos. Foi realizada a avaliação utilizando a USCD antes e depois da sessão, e anotado as frequências cardíaca e respiratória, estado comportamental, dor e desconforto respiratório. **RESULTADOS:** Participaram 26 RNs. Observou-se aumento significativo da amplitude diafragmática (p= 0,02) e da saturação periférica de oxigênio (p= 0,05); os parâmetros fisiológicos permaneceram nos limites da normalidade e a intervenção não provocou desorganização comportamental, dor ou desconforto respiratório aos RNs. **CONCLUSÃO:** A fisioterapia aquática promoveu aumento da amplitude diafragmática, sugerindo que esta técnica pode ser utilizada como forma de estimular a contração da musculatura respiratória em RN, além de se mostrar uma técnica segura, pois não gerou instabilidade clínica, desorganização comportamental, dor ou desconforto respiratório aos participantes.

PALAVRAS-CHAVE: Hidroterapia. Fisioterapia Aquática. Ultrassonografia. Diafragma. Recém-nascido.

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1. Introduction

During pregnancy, the fetus has an environment in the womb that is ideal for its development, with controlled temperature, filtered light and sound stimuli, and the presence of the amniotic sac, which is filled with fluid of high density, providing broad and rich spontaneous movement, free of gravity. The uterine walls and placenta provide restraint and establish physical boundaries that keep the fetus in a flexed and aligned position, which is crucial for its typical structural development.[1-3]

Born before 37 weeks, the newborn (NB) can be admitted to a neonatal intensive care unit (NICU) and, during hospitalization, is exposed to stimuli and procedures necessary to ensure their survival, which can cause pain and discomfort.[1,2] As a response to this stress, it causes cardiorespiratory, hormonal, and behavioral changes, endangering its physiology and the functioning of its subsystems (motor, behavioral conditions, attention/interaction, and regulatory).[1,3,4]

In addition, the respiratory mechanics of the NB suffer disadvantages due to the immaturity of the respiratory muscles, a highly compliant rib cage with horizontal ribs, in addition to the diaphragm, the main inspiratory muscle, whose structure has muscle fibers with little reserve and is more prone to fatigue, which when it contracts, moves caudally, increasing the size of the rib cage, decreasing pleural pressure, increasing abdominal pressure and consequently transdiaphragmatic pressure (Pdi), which is the difference in pressure in the abdominal and chest cavities, causing air to enter the lungs.[5,6]

Respiratory function depends on the mobility of the diaphragm, with the ideal length-tension ratio, and efficient interaction with the abdominal muscles.[7] It is known that the diaphragm is responsible for three-quarters of the increase in lung volume during silent breathing[8], and in healthy individuals, there is a moderate correlation between diaphragm excursion and markers of pressure-generating capacity.[9] The contractile efficiency of the diaphragm is directly proportional to gestational age (GA) at birth; the higher the GA, the higher the Pdi or maximum inspiratory pressure (PImax).[5] In addition, hospitalized NBs suffer from various respiratory pathologies that affect respiratory biomechanics, interfering with the respiratory system.[1,6]

To prevent and rehabilitate dysfunctions resulting from the treatments the NB is exposed to and the length of hospitalization in the NICU, physiotherapists have at their disposal strategies based on humanized care, such as aquatic physiotherapy.[4] This, according to Anjos[4], seeks to simulate the sensations experienced inside the mother's womb, providing relaxation, safety, and body boundaries for NBs. The liquid environment facilitates spontaneous movement, promotes proprioception, postural organization, and in association with the application of heat, there is an increase in circulatory flow, decreasing muscle spasms with consequent muscle relaxation, reduction of pain and stress, favoring proper functioning of the musculoskeletal system and of the behavioral and physiological state of the organism.[3,4,10]

The benefits of aquatic physiotherapy on pain control, behavioral state, and physiological parameters in newborns have already been described, but little has been studied about its effects on the respiratory system, especially diaphragmatic function. It is known that lung mechanics are altered when the body is immersed at the level of the C7 vertebra, as the respiratory muscles are loaded with hydrostatic pressure during inhalation, making it an exercise for these muscles.[10] The diaphragm moves in a cephalic direction, causing a decrease in vital capacity, functional residual capacity, and expiratory reserve volume, added to the action of hydrostatic pressure on the rib cage, immersion generates an increase in respiratory work.[11] However, there are no studies that measure diaphragmatic excursion after immersion in water.

One way of assessing diaphragmatic movement is with the diaphragmatic kinesiologic ultrasound (DKUS). The use of ultrasound to assess respiratory muscle pump function is relatively new.[12] It is a non-invasive, ionization-free test that can be performed at the bedside for evaluation and monitoring. It provides accurate real-time information, with data that can be useful in guiding the choice of techniques and parameters for respiratory physiotherapy.[13] Over the last few years, circumstantial evidence suggests that respiratory muscle monitoring can interfere with clinical care in the intensive care unit (ICU).[14]

Therefore, the aim of this study was to evaluate the effect of aquatic physiotherapy on the diaphragmatic function of newborn babies, measuring diaphragmatic amplitude using the DKUS, as well as assess the safety of aquatic physiotherapy on the clinical stability of the participants, monitoring their physiological and behavioral responses, level of respiratory discomfort and the presence of pain of the NB to intervention.

2. Methods

This is a before-and-after, cross-sectional clinical trial. Each participant received an aquatic physiotherapy intervention and evaluation by the DKUS before and after.

2.1 Participants

The study was performed between January and July 2022, with NBs admitted to the NICU of a university hospital. Those responsible for the participants signed the Free and Informed Consent Form (FICF), which was previously approved by the Research Ethics Committee of the hospital where the study was performed.

NBs with a gestational age of at least 30 weeks, weighing at least 1250 grams at the time of the intervention, between 7 and 28 days old, clinically stable, on full enteral nutrition, in the process of daily weight gain, on oxygen therapy or in room air and normothermic (temperature between 36.4 and 37.8) were included. NBs were excluded if they had: hemodynamic instability, invasive devices (central and peripheral venous access, umbilical catheter, gastrostomy, plastic, or metal tracheostomy), the presence of umbilical cord remnants, skin lesions, infectious diseases, and the presence of orthopedic immobilization.

2.2 General procedures

After selecting the participants suitable for the study, data was collected from the respective medical records to characterize the sample, such as name, weight and gestational age at birth, corrected weight and age at the time of collection, feeding route, clinical diagnosis, use of supplementary oxygen and other variables, such as vital signs (axillary body temperature, heart and respiratory rates, and peripheral oxygen saturation), scales Neonatal Infant Pain Scale (NIPS-Brazil), Silverman-Andersen Report Card (RSS), Brazelton's adapted sleep-wake cycle assessment scale, and DKUS assessment. Before handling the NB in the hot tub, initial assessment data was collected, followed by intimate hygiene and containment of the NB with the fabric. After aquatic physiotherapy, all the variables were reassessed, with the DKUS being the last assessment, performed 15 minutes after the end of therapy.

2.3 Specific procedures

To assess diaphragmatic amplitude, an ultrasound device was used — Sonosite, model M-turbo. The NB was kept in dorsal decubitus, restrained with the hands of one of the evaluators, keeping the head centralized and the lower limbs flexed. A convex transducer positioned on the right subcostal line was used, using the liver as an acoustic window and visualization in B-mode measured in M-mode. After freezing the image, 3 waves of diaphragmatic incursions were selected, and the amplitude was measured from the base to the peak of each wave and was measured by two evaluators.

Physiological parameters were monitored by measuring axillary body temperature (ABT – normal values between 36.5 and 37.2°C) using a digital axillary thermometer. Heart rate (beats per minute – bpm; 110 to 170 bpm) and peripheral oxygen saturation (SpO_2 – 91 to 95%) were obtained using a pulse oximeter of the brand Covidien Nellcor. Respiratory rate was counted for 1 minute (40 to 60 incursiosn per minute - ipm).[15]

The NIPS scale was used to assess the presence of pain in NBs. Six items are analyzed (facial expression, crying, breathing, arms, legs, and state of consciousness), with scores ranging from 0 to 2 for each item. The total score ranges from 0 to 7, and pain was present if the score was above 3.[16]

Respiratory effort was quantified using the RSS, which assesses the following parameters: upper intercostal retraction, lower intercostal retraction, xiphoid retraction, nasal wing beat, and expiratory moan. Each parameter is scored from 0 (no respiratory changes) to 2 (significant respiratory changes). The sum of all the parameters indicates the child's respiratory status, with 0 being the absence of respiratory distress, 1 to 3 considered mild distress, 4 to 6 moderate and equal to or above 7 severe respiratory distress.[17]

The behavioral state was defined according to the modified Brazelton scale, which assesses different states of sleep and alertness: (1) deep sleep, no movements, and regular breathing; (2) light sleep, eyes closed with some body movement; (3) drowsy, eyes opening and closing; (4) inactive alertness, awake, eyes open with minimal body movements; (5) active alertness, fully awake with vigorous body movements and (6) crying.[18]

2.4 Environmental preparation

The protocol was performed 90 minutes after breastfeeding. Aquatic physiotherapy was performed in a bucket, which was filled with approximately 5 liters of water, with a temperature between 36.6 and 37.5°C, measured with a bath thermometer. The immersion time was set at 10 minutes. The NB was held with a soft cloth up to shoulder height, without a diaper, keeping the body in a flexed posture. The researcher held the participant by placing one hand on the cervical region and the other on the sacral region, maintaining the flexor pattern, and gently placing them in the bucket, slowly immersing them in an upright posture with their feet down until the water was at shoulder height. After an adaptation period in the water, the researcher positioned his hands to the side of the NB's head, keeping it submerged by means of assisted flotation. The researcher performed gentle anteroposterior and latero-lateral movements of the NB's body, respecting the NB's spontaneous movement.

After 10 minutes of immersion, the researcher removes the NB from the bucket in a flexed posture, quickly wrapping it in a soft cloth, allowing no loss of body temperature. Fifteen minutes after the end of the aquatic physiotherapy, a new assessment of vital data was performed, and then the DKUS.

2.5 Statistical analysis

After collection, the data was transferred to a spreadsheet Excel for further analysis by the software Statsoft ®. To calculate the sample size, the main question of the study was considered: evaluation of diaphragmatic amplitude before and after aquatic physiotherapy. The equation used to compare two groups with paired samples and quantitative variables, with a significance level of 0.05, considered a sample size of 26 participants. The DKUS evaluation was performed by two trained physiotherapists, and an agreement test was conducted between the evaluations.

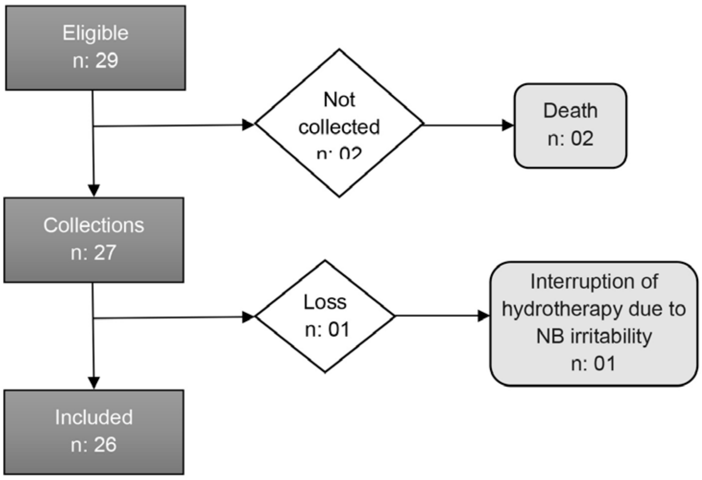
The Shapiro-Wilk test was used to check the normality of the variables. The paired T-test was used for variables that followed normality, and the Wilcoxon test for variables that did not follow normality. Linn's intra-observer agreement coefficient was used to assess the reliability of the ultrasound evaluation.

This study was approved by the Research Ethics Committee of the hospital where the study was performed (under CAAE 52216521.5.0000.0096 and protocol number 5.075.270) and is registered with the Brazilian Registry of Clinical Trials (ReBEC) under code RBR-4kfh2bk.

3. Results

The procedure for selecting participants is described in the flowchart shown in Figure 1.

Figure 1. Flowchart for including participants in the research



Source: the authors (2023).

Twenty-six newborns participated in the study. Their characteristics at birth and at the time of collection are represented in Table 1. Those born between 28 and 31 weeks and 6 days were considered very premature, those born between 32 and 33 weeks and 6 days were considered moderately premature, those born between 34 and 36 weeks and 6 days were considered late premature, and those born at term were the ones born after 37 weeks gestational age at birth.[19]

Table 1. Characteristics of the sample according to gestational age at birth and at collection, classification of degree of prematurity, weight at birth and at collection, classification of weight according to gestational age, ventilatory support at collection and total length of stay (n= 26)

	n	
GAB (sem.) (mean ± SD)		33.8 (± 2.5)
Very premature (%)	5	19.23
Moderate preterm (%)	11	42.31
Late preterm (%)	7	26.92
Newborn term (%)	3	11.54
Birth weight (g) (mean ± SD)		1.875,20 (± 523.90)
AGA (%)	17	65.38
SGA (%)	8	30.77
LGA (%)	1	3.85
Days of life at collection (mean ± SD)		18.7 (±5.4)
GAB (sem.) (mean ± SD)		36.3 (± 2.0)
Weight at collection (gr) (mean ± SD)		2.001,00 (± 465.20)
Breathing in ambient air (%)	23	88.46
With oxygen therapy (%)	3	11.54
Length of stay in the NICU (Med in days) (min–max)		30 (9–47)

GAB: Gestational age at birth; AGA: Adequate for gestational age; SGA: Small for gestational age; LGA: Large for gestational age; NICU: Neonatal Intensive Care Unit; sem.: weeks; SD: standard deviation; g: grams; Med: median.
Source: the authors (2023).

To assess diaphragmatic mobility using the DKUS, the paired T-test was used between the values measured before and after aquatic physiotherapy. A statistically significant difference between the groups is p-value < 0.05. There was a significant increase in diaphragmatic amplitude (p= 0.02) and SpO2 (p= 0.05). The physiological parameters remained stable, fluctuating within normal limits, such as a 0.1° increase in ABT and 4.6 bpm in HR, as well as a 2.5 ipm reduction in RR after the intervention, all of which were not statistically significant. All the values are shown in Table 2, divided by group before and after aquatic physiotherapy.

Table 2. Diaphragmatic amplitude by US and physiological parameters before and after aquatic physiotherapy (n= 26)

Parameter	Before (Mean ± SD)	After (Mean ± SD)	p
Diaphragmatic amplitude (mm)	4.4 (±1.74)	5.4 (±1.38)	0.02
SpO2 (%)	95.8 (± 2.9)	97.1 (± 2.0)	0.05
ABT (°C)	36.7 (± 0.2)	36.8 (± 0.4)	0.8
HR (bpm)	142.3 (± 18.6)	146.9 (± 15.6)	0.2
RR (ipm)	51.2 (± 11.8)	48.7 (± 11.5)	0.3

Legend: mm: millimeters; SpO2: peripheral oxygen saturation; ABT: Axillary body temperature; HR: heart rate (beats per minute); RR: respiratory rate (inhalations per minute); Statistical test: T Student.
Source: the authors (2023).

After the intervention, none of the participants had any pain, and the level of respiratory discomfort did not change significantly. The behavioral state was more active after the protocol (p=0.03), but at a level that does not characterize behavioral disorganization, as shown in Table 3.

Table 3. Assessment of pain using the NIPS scale, level of respiratory discomfort assessed by the BSA, sleep and wakefulness using the Brazelton scale (n= 26)

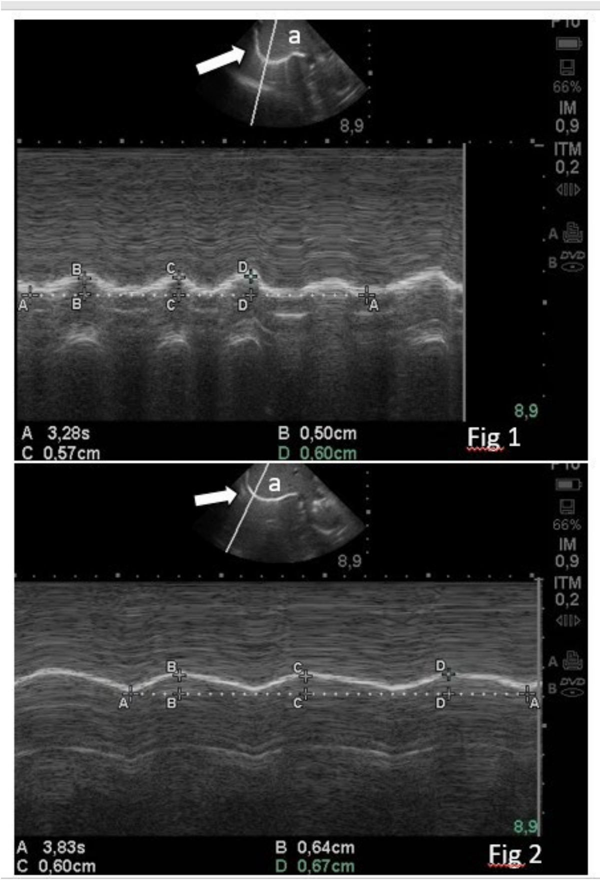
Parameter		Before	%	After	%	p
NIPS	Yes	1	3.85		0	1
	No	25	96.15	26	100	
RSS	No discomfort	17	65.38	16	61.54	1
	Light	9	34.62	10	38.46	
Brazelton	Deep sleep	8	30.77	2	7.69	0.03
	Light sleep	9	34.62	6	23.08	
	Drowsy	4	15.38	9	34.62	
	Awaken	3	11.54	9	34.62	
	Active alert	2	7.69		0	

Legend: Nips: Neonatal Infant Pain Scale; RSS: Silverman-Andersen Respiratory Severity Score; Brazelton: sleep-wake cycle assessment scale; Statistical test: Pearson chi-square.
Source: the authors (2023).

To assess the agreement between the two diaphragmatic amplitude evaluators, the Lin's Concordance Correlation Coefficient test was used, which assesses the reproducibility of the measurements, with a value of 1 indicating maximum agreement. Using Lin's coefficient of agreement, an estimate of 0.98 and a 95% confidence interval of 0.948-0.992 were found.

Figure 2 shows the ultrasound image of diaphragmatic excursion amplitude before and after aquatic therapy. We used the liver as an acoustic window and the diaphragm appears as a hyperechoic line. To measure, we drew a Line A to mark the start of the diaphragm's contraction. Next, we measured three consecutive respiratory movements, represented by points B, C, and D.

Figure 2. M-mode ultrasound image of the diaphragm and diaphragmatic excursion before and after aquatic therapy



Legend: a: Liver → Diaphragm.
Source: the authors (2023).

4. Discussion

Aquatic physiotherapy increased diaphragmatic amplitude in hospitalized term and premature NBs evaluated by the DKUS, reflecting an increase in peripheral oxygen saturation. The other physiological parameters remained within the normal range, with no pain or respiratory discomfort and a more active behavioral state compared to before the aquatic physiotherapy. The result found may be related to the response of the diaphragm during immersion, since lung mechanics are influenced by hydrostatic pressure, with resistance at the moment of inspiration and consequently a greater load on the inspiratory muscles, especially the diaphragm.[11]

For the pediatric public, the study by Braga et al.[20] evaluated the effects of aquatic physiotherapy on the PImax of children with an average age of 12 with Down's Syndrome and also found a significant increase after 10 hydrotherapy sessions. In the study by Ho et al.[21], which compared spirometry evaluations with DKUS in healthy children and adolescents, a positive relationship was found between diaphragm excursion, spirometry, and respiratory pressures. In the study by Sandi and Silva[11], an increase in maximum inspiratory pressure (PImax) was found with manovacuometry in healthy young people after 20 minutes of body immersion at shoulder level, without specific exercises, demonstrating that body immersion can increase inspiratory muscle strength.

Regarding the assessment of diaphragmatic amplitude by the DKUS, knowing the patient's diaphragmatic Mobility helps direct the treatment and the benefits generated. They also report that even small changes in the movement of the main breathing muscle can have repercussions on pulmonary ventilation and, consequently, on the performance of activities of daily living.[12]

The results obtained corroborate with aquatic physiotherapy studies performed in a hospital environment by Tedesco et al.[22] and Novakoski et al.[23], who found an increase in peripheral oxygen saturation, observed after aquatic physiotherapy. Possible explanations are related to the relaxation offered by heated water, capable of improving the diaphragmatic muscles[23] and, due to the hydrostatic pressure of the water on the immersed body, increase the pressure in the venous return system[11], directing blood from the lower limbs to the chest region, with a consequent increase in pulmonary blood flow, favoring better gas exchange, resulting in an increase in peripheral oxygen saturation.[24,25]

Physiological parameters remained stable before and after aquatic physiotherapy. There was no damage to the thermoregulation of the participants, as the aquatic physiotherapy was performed at a water temperature like the NB's body temperature (36.5–37°C), a result also found by Fonseca Filho et al.[26] and Tedesco et al.[22] HR and RR oscillations were not significant, remaining within normal limits. In the studies by Tedesco et al.[22] and Novakoski et al.[23], aquatic physiotherapy did not destabilize the physiological parameters of the participants. We associate these findings with the effects of heated water, which causes muscle relaxation, improves comfort, and can reduce stress-related hormone levels, promoting psychophysiological relaxation for NBs.

Associated with these results, there was no pain, no increase in respiratory discomfort, and the behavioral state remained at levels that do not characterize behavioral disorganization after aquatic physiotherapy. Such findings are in line with studies by Tedesco et al.[22], Novakoski et al.[23], and Lemos.[27] These benefits are provided by the therapeutic effects of heated water, such as vasodilation and increased peripheral circulation, as well as a reduction in muscle spasm, with consequent general muscle relaxation, reducing cortisol levels. Aquatic physiotherapy provides adequate stimulation, promoting better organization and adaptation to the environment, and the liquid environment also causes relaxation, possibly because it reminds the NB of the intrauterine environment.[23,26,28] All these variables demonstrate the safety of performing aquatic physiotherapy on NBs, maintaining their clinical stability before and after the intervention.

Linking the results found in this study with the results of the studies quoted above, we can suggest that aquatic physiotherapy was a way of stimulating the contraction of the diaphragmatic muscles, acting positively on the respiratory work of NBs, as it generated a significant increase in diaphragmatic amplitude, without triggering respiratory effort or pain, and also led to an increase in SpO2, results which are of important clinical relevance.

However, no studies were found that used diaphragmatic assessment by the DKUS with aquatic physiotherapy as an intervention. There is a need for more studies, with larger samples, that assess the diaphragm by DKUS, as well as evaluate the benefits of aquatic physiotherapy in the long term, such as weaning or oxygen independence, in order to deepen knowledge in this context.

5. Conclusion

In conclusion, aquatic physiotherapy promoted a significant increase in diaphragmatic amplitude, as well as an increase in SpO2, without causing clinical instability in NBs or generating pain or behavioral disorganization. It is suggested that aquatic physiotherapy is beneficial for NBs over 30 weeks of gestational age. It can be used as a way of stimulating the contraction of the diaphragmatic muscles, in addition to the effects already known, such as the sensory-motor stimulus provided by the environment, which is reminiscent of the intrauterine experience, promoting behavioral organization and reducing stress.

Authors' contributions

Liberato KC participated in the collection, formulation of the hypothesis, conception, design of the study, analysis, interpretation of the data, and writing of the manuscript. Andreazza MG and Assis MS worked in the collection, in the formulation of the hypothesis, conception, study design, writing, revision of the manuscript, and final approval of the version to be published. Sarquis ALF, Kovelis DM, and Israel VL contributed to the formulation of the hypothesis, design, study design, manuscript review, and final approval of the version to be published. Lima MN participated in the analysis, interpretation of the data, revision of the manuscript, and final approval of the version to be published. Gomes EO worked on the conception of the project, the formulation of the hypothesis, the design of the study, the final revision of the manuscript, and the final approval of the version to be published.

Conflicts of interest

No financial, legal, or political conflicts involving third parties (government, private companies and foundations, etc.) have been declared for any aspect of the submitted work (including but not limited to grants and funding, participation in advisory boards, study design, manuscript preparation, statistical analysis, etc.).

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