# Greater abdominal muscle thicknesses and a smaller inter-recti distance at late pregnancy are related to better cord blood gas values. A cross-sectional study from the GESTAFIT project.

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### Abstract

Objectives: The aim of this study was to explore the associations of abdominal muscles thickness and inter-recti distance (IRD) at late pregnancy with birth-related outcomes and umbilical cord blood (CB) gas values. Design: cross-sectional study. Setting: Sport and Health University Research Institute Sample: One hundred and fifty-two pregnant women. Main outcome measures: The thickness of the abdominal muscles (transverse abdominis [TrA], internal [IO] and external obliques [EO]) and the IRD were measured by ultrasound at the 34th gestational week. Birth outcomes were collected from obstetric medical records. Umbilical CB gas concentrations were assessed after birth using a blood analyzer. Results: Greater TrA and IO thickness were associated with a higher venous CB PO2 value, both at muscular rest (respectively, $p<0.01$ and $p<0.05$) and during activation (both $p<0.05$). A greater activated TrA thickness was associated with a higher venous CB oxygen saturation ($p<0.05$). EO thickness at rest was positively related to arterial CB pH ($p<0.05$), and during activation to the 1-minute Apgar test ($p<0.05$). A greater IRD was associated with higher arterial (at rest $p<0.01$; during crunches $p<0.05$) and venous CB (at rest, $p<0.05$) PCO2 values, and with lower arterial CB PO2 ($p<0.05$), arterial CB oxygen saturation (at rest, $p<0.05$; during crunches $p<0.01$), and venous CB oxygen saturation (during crunches, $p<0.05$, and lower venous pH ($p<0.05$). Conclusion: Greater abdominal muscle thicknesses and a smaller IRD at late pregnancy are related to better umbilical CB gas values at birth. ClinicalTrials.gov Identifier: NCT02582567

## INTRODUCTION

The abdominal musculature undergoes morphological and functional changes during pregnancy[1]. For instance, the inter-recti distance (IRD) increases, especially in the third trimester[2], while other stabilizing muscles of the lumbar spine, such as the transverse abdominis (TrA) and the internal oblique (IO) and external oblique (EO)[3] muscles, tend to become thinner as pregnancy progresses[4]. A number of studies have explored the associations shown between such changes in the abdominal muscles during pregnancy, and lower back pain[4], pelvic symptoms[5], and quality of life[6], and with pelvic floor status[7] in the postpartum period. Others have focused on the role of pelvic floor muscles on birth outcomes[8]. However, despite the fact that the abdominal muscles play an important role during labor[9], little is known about their influence on birth-related outcomes.

The second stage of labour begins with the full dilation of the cervix and ends with the birth of the baby.

It includes a passive phase, in which the descent of the foetus takes place, and an active phase, during which the mother voluntarily pushes the foetus through the birth canal[10]. The successful delivery of the baby therefore depends on both uterine contractions and maternal abdominal effort[9]. Excessive stretching of the abdominal muscles during pregnancy has been previously associated with a reduction in contractile strength[11], and interestingly, a larger diastasis recti has been associated with poorer electromyographic readings for the rectus abdomini muscles during labour[12].

There are other pathways, however, via which maternal muscle status might influence birth outcomes. For example, muscles also have an important endocrine function via the secretion of myokines that can improve vascular endothelial function[13], perhaps leading to better placental and umbilical cord blood (CB) flow during birth. Thicker abdominal muscles might, therefore produce more myokines, further improving these variables.

The aim of the present work was to explore the associations shown by the thickness of abdominal muscles and the IRD at the 34$^{th}$week of gestation (w.g.), with the duration of the first and second stages of labour, the neonatal Apgar test score, and umbilical CB gas values at birth.

## METHODS

### Study design and participants

The present cross-sectional study forms part of the GEStation and FITness (GESTAFIT) project, the methodology of which has been explained in detail elsewhere[14]. A total of 384 pregnant women were informed about the study during their first visit to a gynaecologist at the hospital in the 12$^{th}$ week of gestation (w.g.); 159 women who met the inclusion criteria were eventually recruited to the study (**Supplementary Table S1)** . In adherence to the CONSORT statement[15], all provided written, informed consent to be included. The broader GESTAFIT study involved subjects taking part in an exercise program, or following their normal lifestyle, thus requiring the present results be appropriately adjusted (see below).

### Procedures

The enrolled subjects' sociodemographic, clinical and anthropometric characteristics, and flexibility, were assessed at the 16$^{th}$ w.g. Flexibility, height and weight were measured again at the 34$^{th}$ w.g., along with abdominal muscle thicknesses and the IRD. Birth and obstetric outcomes (duration of labour, gestational age, type of birth, birth weight) were collected from the subjects' Pregnancy Health Documents and digital medical records. Umbilical cord blood was collected at birth.

*Maternal sociodemographic and clinical data*

Sociodemographic data (age, educational and working status), reproductive history, and clinical information (suffering or having suffered specific diseases, medication), were assessed using a self-reported questionnaire. The research team was present at all times to provide explanations and instructions.

*Maternal anthropometric assessments*

Height and weight were measured using a SECA 22 stadiometer (Seca, Hamburg, Germany) and an InBody R20 scale (Biospace, Seoul, Korea), respectively. The body mass index (BMI) was calculated as: *weight (kg)/height* $(m^2)$ .

*Pregnancy health document: obstetric and gestational history*

Obstetric and gestational history data were collected via the Andalusian Regional Government's Pregnancy Health Document. Given to all pregnant women in Andalusia at their first appointment with their midwife, it collects information on previous pregnancies and births, and on the patient's gynaecological history and current pregnancy. Gestational age was calculated from the date of last menstruation corrected for cycles of 28 days, and subsequently corrected by ultrasound if needed[16]. The result was used to time the assessments made in the 16$^{th}$ and 34$^{th}$ w.g.

*Physical fitness: flexibility*

Flexibility was assessed via the Back Scratch test[17]. This consists of measuring the overall range of shoulder motion via the distance between the middle fingers of each hand when trying to connect them behind the back with one arm over the shoulder (performed standing). This test was done twice over both shoulders and the final score calculated as the mean between the best attempts at each[17].

*Abdominal muscle thicknesses*

An Aplio 500 ultrasound machine (Toshiba, Tokyo, Japan) with a 12 MHz linear probe was used to examine the abdominal musculature (set to scan at a depth of 6 cm with a frequency for musculoskeletal exploration). All images were obtained with subjects relaxed at the end of expiratory movements (**Supplementary Figure S1)** . The lateral abdominal musculature (TrA, IO and EO) was examined following a previously described protocol adapted for use with pregnant women[4]. Subjects adopted the supine decubitus position with a foam roller under the knee joint to ensure that the legs were flexed (hip at $30^{o}$); a pillow was placed under the head to facilitate relaxation of the abdominal musculature. The probe was placed between the iliac crest and the last rib in the mid-axillary line. Measurements were taken 1 cm from the insertion edge of the transverse fascia - one at rest and one during activation (for which the subject was instructed to make the movement for pulling up a vaginal tampon with the perineal musculature). The mean muscle thicknesses on each side were then determined and overall means calculated.

The IRD was measured with the subject in the same position. The probe was placed transversely across the midline of the abdomen, 2 cm above the umbilicus. Measurements were taken at rest and during activation, for which the subject performed a gentle crunch lasting about 3-5 s. The position for taking the measurement was marked on the skin to standardize the position of the probe. Since there is no consensus regarding the cut-off point for diastasis recti in pregnant women[2,18,19], subjects were classified as above or below the $50^{th}$ percentile (i.e., median) of the IRD, both at rest and during crunches.

*Birth outcomes: data collected on the day of birth*

All data related to the type of birth (eutocic, instrumental or caesarean), gestational age at birth, use of epidural analgesia, length of each stage of labour, offspring sex and weight were obtained from perinatal obstetric records (partogram) and from other records made after birth.

*Umbilical cord blood gas*

A trained midwife double clamped the umbilical cord within three minutes of birth (minimum distance between clamps = 10 cm). Blood samples were taken from both the umbilical artery and vein using a pre-heparinized 1 mL syringe. The partial pressure of carbon dioxide ($PCO_2$), partial pressure of oxygen ($PO_2$), oxygen saturation, and pH of both samples were analyzed using a GEM Premier 4000 blood analyzer (GEM Premier 4000: Instrumentation Laboratory, Bedford, MA,)[20].

**Statistical analyses**

Subject sociodemographic and clinical characteristics, and abdominal muscle thicknesses, were recorded using descriptive statistics (mean±SD, number, or percentage as required). Since some variables (onset of labour, type of birth, sex of the baby) have been shown weakly related to the study variables[21,22], their role as potential confounders was assessed. Finally, the associations shown by the thickness of the abdominal muscles and the IRD, with birth-related maternal and neonatal outcomes, were determined using partial Pearson correlations after adjusting for maternal age, parity, BMI at the $16^{th}$ w.g., and gestational age at birth. Values for the duration of the first and second stages of labour, the Apgar test score, and CB gas variables were adjusted for epidural analgesia. Given that our group has previously described an association between maternal flexibility in the third trimester of pregnancy and CB gas values at birth[23], the latter variables were adjusted for flexibility at the $34^{th}$ w.g. Analysis of covariance (ANCOVA) was used to explore the differences in the duration of the first and second stages of labour, and in neonatal CB gas values, between women above or below the median IRD. Adjustments were also made for being in the control or exercise group within the broader GESTAFIT project[14]. All statistical analyses were performed using SPSS Software for Windows, v.20.0 (IBM, Armonk, NY, USA). Significance was set at p[?]0.05.

## RESULTS

Of the subjects who met the eligibility criteria and agreed to participate, 159 completed the first assessment (**Figure 1** ). Among them, 158 (age 32.9+-4.6 years, BMI 24.9+-4.1 kg/$m^2$) provided sociodemographic data and were included in the present analyses. **Table 1** shows these data along with the subjects' clinical characteristics. Most of the study subjects (97.5%) lived with a partner and had a university degree (60%). Almost all gave birth at a public hospital (94%) at around the $40^{th}$ w.g; approximately 60% of all births were eutocic. At the $34^{th}$ w.g., the IRD $50^{th}$ percentile was 46.3 mm at rest and 40.7 mm during crunches. **Table 2** shows the Pearson partial correlations between the average abdominal muscle thickness at $34^{th}$w.g. and maternal and neonatal birth outcomes. After adjusting for the aforementioned confounders, abdominal muscle thickness and IRD were found not to be related to the duration of the first and second stages of labour (all $p$ >0.05). Greater TrA and IO thicknesses were associated with higher venous CB $PO_2$ at rest (r=0.326 $p$ =0.005, and r=0.261 $p$ =0.0027, respectively) and during activation (r=0.249, $p$ =0.037, and r=0.257$p$ =0.031, respectively). A greater TrA thickness during activation was associated with a higher venous CB oxygen saturation (r=0.235,$p$ =0.05). EO thickness at rest was positively associated with arterial CB pH (r=0.256 $p$ =0.031), and in activation with the newborn's 1-minute Apgar test score (r=0.216 $p$= 0.029). A greater IRD was associated with a higher arterial CB $PCO_2$ (at rest, r=0.302 $p$ = 0.01; during crunches, r=0.242 $p$ =0.042) and venous CB $PCO_2$ (at rest, r=0.246 $p$ =0.028), and lower arterial CB $PO_2$ (at rest; r = -0.256$p$ =0.041; during crunches r=-0.287 $p$ =0.021), arterial CB oxygen saturation (at rest, r=-0.264 $p$ =0.038; during crunches r=-0.313 $p$ =0.01), and venous CB oxygen saturation (during crunches, r=-0.251 $p$ =0.039), and a more acidic arterial CB pH (during crunches, r=-0.231 $p$ =0.05) and venous pH (at rest, r=-0.225 $p$ =0.041; during crunches, r=-0.240 $p$ =0.039).

No differences were seen between subjects with an IRD above or below the median in terms of the duration of the first and second stages of labour, or in terms of their offsprings' Apgar test scores (data not shown). **Figure 2** shows the differences in CB gas values for the subjects with IRD above and below the median value. After adjusting for potential confounders, neonates born to women with an IRD during crunches equal to or greater than the median value had arterial CB with a more acidic pH (**Figure 2A,** $p$ =0.038), a higher $PCO_2$ (**Figure 2B,** $p$ =0.029) and a lower $PO_2$ (**Figure 2C,** $p$ =0.005) and oxygen saturation (**Figure 2D,** $p$ =0.004) than did those born to women with an IRD below the median. Finally, the offspring born to women with an IRD at rest equal to or greater than the median showed a lower arterial CB $PO_2$ (**Figure 2E,** $p$ =0.041) than did those born to women with an IRD at rest below the median. No differences were seen with respect to the duration of the first and second stages of labour, or any other CB gas values (all$p$ >0.05, data not shown).

## DISCUSSION

### Main Findings

The results show that the thickness of the TrA and IO muscles (both at rest and during activation) is positively associated with venous CB $PO_2$ values. Similarly, a greater IRD is associated with a more acidic pH and lower oxygen saturation in both arterial and venous CB. It is also noteworthy that the offspring born to women with a greater IRD had higher arterial and venous CB $PCO_2$ and lower pH, and a lower arterial CB oxygen saturation. Moreover, the offspring of the subjects with an IRD above the median had poorer CB gas values.

### Strengths and Limitations

This study suffers from a number of limitations. First, its cross-sectional design precludes any confirmation of causality. However, it is implausible that cord blood gas status should have an influence on abdominal musculature. Second, reductions in the sample size for some variables could have prevented significance being reached for some associations. The study also has some strengths that should be highlighted. First, the measurement of gases in the arterial CB is the gold standard for examining the acid-base status of the foetus. Second, venous and arterial CB samples were taken to allow for better interpretation of the results. Third, muscle thicknesses and the IRD were measured by ultrasonography - a reliable and risk-free method for pregnant women[24]. Finally, to the best of our knowledge, this is the first study providing a comprehensive examination of the associations shown by objectively measured abdominal muscle thickness and the IRD, with cord blood gases at birth.

### Interpretation

Alterations in the functionality of the abdominal muscles resulting from pregnancy-induced morphological changes have long been known[25], and it has been proposed that women with stronger abdominal muscles might push more effectively, shortening the second stage of labor[26]. A prolonged second stage has been associated with adverse birth outcomes, including a greater risk of perinatal asphyxia[27]. However, in the present work, no association was seen between any abdominal muscle thickness and the duration of labour. This suggests that the improved CB gas values observed in offspring born to women with greater abdominal wall muscle thicknesses is due to metabolic rather than structural mechanisms. Uterine contractions during labour induce metabolic stress in the foetus, which is reflected in CB gas values at birth[28].

In the present work, the subjects with a thicker EO at rest had newborns with less acidic cord arterial blood, which agrees with the association seen between a greater EO thickness during activation and a better 1-minute Apgar test score. Reductions in the pH of the arterial CB are generally related to acute labour difficulties, such as an acute occlusion of the umbilical cord.[29]

Acidosis in the umbilical artery can lead to vasoconstriction in the peripheral tissues (mostly) of the foetus[30]. Importantly, the present results suggest that babies born to mothers with greater abdominal muscle thicknesses are better oxygenated, as shown by the venous CB in particular; gas values measured in the venous CB reflect the concentration of oxygen originally provided to the fetus[29]. The mother's skeletal muscle might play a role in the oxygenation of the cord blood via the release of myokines, which could cause vasodilation in the placental blood vessels[31]. Certainly, the myokines released by muscle tissue are known to protect against ischemia in angina[32]. Although no study has specifically examined the association between maternal myokines and birth outcomes, a systematic review[33] suggests that myokines may act as signalling molecules between maternal skeletal muscle and the placenta, regulating maternal–foetal blood flow. Further studies on myokine levels and their association with abdominal muscle thickness in pregnant women are needed to better understand the mechanisms behind the present findings.

A greater IRD, both at rest and during crunches, was related to a higher $PCO_2$, a lower $PO_2$, and lower oxygen saturation in the arterial CB, and a more acidic pH for the venous CB. In addition, neonates born to mothers with a higher IRD during crunches had a lower venous CB oxygen saturation. These results confirm that a smaller IRD is associated with greater oxygenation of the foetus at birth. However, no association was seen between the IRD and any other birth outcomes, such as the Apgar test score or the duration of labour. This agrees with that described by Oliveira et al.[12]In contrast to the present findings, the latter authors found no association between IRD and CB pH or $PCO_2$[12]. These differences might be attributable to the fact that the latter study involved a smaller sample (n=24).

No cut-off has been established for diagnosing rectus diastasis in pregnant women. Indeed, the literature quotes the use of cut-off points at 2 cm above the umbilicus ranging from 20 to 86 mm[19,34,35]. For this reason, and following the criterion used in a previous study[35], the IRD $50^{th}$ percentile was used in the present work as a cut-off to explore whether there was any relationship between IRD and birth outcomes. Most of the previously discussed associations with IRD were maintained only for women with an IRD above the median during crunches. Being above the median was also associated with poorer CB gas values, but not with the rest of the studied birth outcomes. Although the literature contains no studies with which to reliably compare the present results, the finding of the above associations during crunches could be clinically important. Maternal pushing during the second stage of labour usually involves crunching to assist the baby's descent through the birth canal. Therefore, the ability to reduce the IRD at this stage might be decisive in improving the oxygenation of the foetus. Further studies exploring the influence of core exercises during pregnancy on the above-described outcomes are needed.

## CONCLUSION

Greater abdominal muscle thicknesses and a smaller IRD during late pregnancy appear to be related to better neonate CB gas values. Further studies are need to determine whether hormones are released in greater quantity by thicker skeletal muscles, and how higher concentrations might affect foetal oxygenation.

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**Disclosure of Interests:** None to declare.

**Contribution to Authorship:** LBG had full access to all of the data in the study, took responsibility for the integrity of the data and the accuracy of the data analyses and interpreted the data and drafted the initial manuscript; OOC, MFA, IRC, PAM, and VAA conceptualized and designed the study, interpreted the data, and collected data. All authors were involved in drafting the article and revising it for important intellectual content. All authors have read and approved the final version of the manuscript and agreed with the order of presentation of the authors.

**Details of Ethics Approval** : The GESTAFIT project was approved by the Clinical Research Ethics Committee (code: GESTAFIT-0448-N-15, approved on 19/05/2015).

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**Table and figure legends**

Table 1. Sociodemographic and clinical characteristics of the study sample

Table 2. Partial correlations of the average abdominal muscle thickness and inter-recti distance (mm) in the third trimester of pregnancy with maternal and neonatal birth outcomes.

Figure 1. Flowchart of the participants for the specific study aims.

Figure 2. Differences in cord blood gas values for the subjects with inter-recti distance above and below the median value.

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Table 1. Sociodemographic and clinical characteristics of the study.docx available at https://authorea.com/users/487407/articles/571971-greater-abdominal-muscle-thicknesses-and-a-smaller-inter-recti-distance-at-late-pregnancy-are-related-to-better-cord-blood-gas-values-a-cross-sectional-study-from-the-gestafit-project

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Table 2.docx available at https://authorea.com/users/487407/articles/571971-greater-abdominal-muscle-thicknesses-and-a-smaller-inter-recti-distance-at-late-pregnancy-are-related-to-better-cord-blood-gas-values-a-cross-sectional-study-from-the-gestafit-project

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Figure 2. Differences in cord blood gas values for the subjects with inter-recti distance above and bel available at https://authorea.com/users/487407/articles/571971-greater-abdominal-muscle-thicknesses-and-a-smaller-inter-recti-distance-at-late-pregnancy-are-related-to-better-cord-blood-gas-values-a-cross-sectional-study-from-the-gestafit-project