Abnormal umbilical cord coiling and association with pregnancy factors

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Abstract

The umbilical cord, as a connecting bridge between two lives, plays an important role in fetal development. Though studies on the umbilical cord date back many years, extensive studies on certain umbilical cord characteristics, such as umbilical cord coiling, are rare. Cord coiling, measured by the umbilical coiling index, is a physiological phenomenon that offers resistance to external pressures. Umbilical cord coiling is a result of several factors, both environmental and genetic. However, umbilical cords sometimes coil abnormally, resulting in hypocoiling, hypercoiling, or non-coiling which have significant associations with adverse perinatal outcomes. An all-language literature search was conducted on Medline from 1970 to 2023. The following search terms were used; umbilical cord; umbilical coiling; coiling index; abnormal coiling; perinatal outcomes, and cross-referencing yielded further information. We comprehensively reviewed the literature on umbilical cord coiling, factors contributing to coiling, abnormal coiling of the umbilical cord, and the association with several factors including maternal age, gravida, gestational diabetes mellitus, pre-eclampsia, abruption, birth weight, intrauterine growth retardation, maternal iron status, small for gestational age, fetal heart rate variations, ponderal index, and sought possible explanations. (J Turk Ger Gynecol Assoc 2024; 25: 44-52)

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Introduction

Normally, the umbilical cord travels from the placenta to the fetal umbilicus, twisting (coiling) as it does so. In 1521, Berengarius noted the umbilical cord vessels' spiral pattern (1). By nine gestational weeks, the umbilical cord's twist, or more correctly, helix, which has been recorded as early as 42 days of gestation, is well-established (2). An umbilical coil is described as one 360° helix of umbilical vessels, which are usually left-oriented (3). Given that the cord's natural tendency to coil implies that there must be a benefit to this from an evolutionary standpoint, the umbilical cord's coiling makes it both flexible and sturdy, and these qualities offer resistance to outside influences that can impair blood flow (4). So abnormal coiling of the umbilical cord has been postulated to be associated with adverse perinatal outcomes. In this review, we aimed to investigate abnormal coiling of the cord and associations of abnormal coiling with various pregnancy factors.

Background

The umbilical cord, also referred to as the navel cord or funiculus umbilicalis, connects the fetus and placenta. By week seven, the umbilical cord is fully formed and replaces the yolk

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sac as the embryo's primary source of nourishment (5). A single umbilical vein and two umbilical arteries are typically seen in the cord, which are enclosed in Wharton's jelly, a supple matrix, rich in proteoglycans (6). This jelly's physical characteristics are comparable to Polyurethane foam, compression- and twist-resistant, and these qualities help in protecting the vital circulatory lifeline that connects the placenta and fetus (7). The placenta delivers nutrient-rich, oxygenated blood to the fetus via the umbilical vein, and umbilical arteries are involved in transportation towards the placenta, thereby allowing the movement of materials to and from without direct mixing. The fetus's health will be seriously compromised if the fetal blood flow through the umbilical cord vessels is compromised (8). The cord is attached to the embryo's ventral surface towards the caudal extremity during the first few weeks of gestation. In the fourth month, the point of attachment is permanently relocated to the centre of the abdomen when the coelom closes and the yolk sac shrinks (9). By six weeks of gestation, an ultrasound can detect the umbilical cord, and by eight to nine weeks, it can be clearly seen. During pregnancy, the umbilical cord is roughly the same length as the fetus's crown-to-rump measurement. At term, the typical length is approximately 50 cm and ranges from 30-100 cm (10).

The arteries and veins of the umbilical cord are distinct from those seen in the rest of the fetus. Internal and external elastic lamina are absent from the walls of the umbilical cord arteries, and mucous connective tissue takes the role of the adventitia that is present in other arteries. An internal elastic lamina, along with a thicker muscularis layer with intertwined smooth muscle fibres make up the umbilical cord vein (11). Doppler velocimetry has been used to examine the blood flow properties of umbilical vessels. The umbilical vein has continuous blood flow, while the umbilical arteries display the distinctive wave pattern which reflects the fetal cardiac cycle (12,13).

Coiling index

Term cords typically have the same number of coils as seen during the first trimester, with the number of coils ranging from 0 to 40, but they can reach as high as 380. This suggests that the cord lengthens by an increase in the pitch between each of its helix turns rather than by an increase in the number of turns (2,14). Four to five per cent of umbilical cords do not coil at all or are poorly coiled (15). After 20 weeks of gestation, 30% of non-coiled cords continue to coil, although a loss of coiling has never been recorded. The fetal side of cords typically exhibits more spiral turns than the placental side (16,17). Coiling can be sinistral (leftward), or dextral (rightward), and occasionally be a mixed pattern, but sinistral is four to eight times more frequent than dextral with no known cause for this leftward bias (4).

In 1954, Edmonds created a system to measure cord coiling. He referred to it as the "Index of twist" since it indicated positive and negative values to the twists based on the direction of coiling (1). This approach was initially simplified by Strong et al. (16) in 1994, through the Umbilical Coiling Index (UCI), which is the ratio of twists to the length of the cord without considering the direction of coiling. However, this method has certain limitations. Every month, the umbilical cord length expands by roughly 3 to 6 cm, with the increase being more pronounced in the second part of pregnancy. As a result, compared to the second trimester, the coiling index is lower in the third trimester. In addition, because various fetuses experience cord lengthening at varying rates, each person's umbilical cord coiling index changes at a different rate. Moreover, different studies have examined the length of the cord in different ways; some studies exclude the segment that is still linked to the newborn (18), while others include all segments of the cord (17). The cord contracts after delivery (19), and so the time between delivery and measurement could affect the UCI and the cord continues to contract following formalin fixation (18). Naturally, the normal mean UCI differs significantly across investigations (20).

The length of the umbilical cord cannot be determined before birth. To measure the coiling index antenatally using ultrasound, a method was developed. This is accomplished by measuring the separation between two neighbouring coils and dividing one by the intercoil distance in centimetres gives the UCI (21). The mean of the UCI was 0.17 coils/cm. The 10^{th} percentile value stood at 0.07 coils/cm and the 90^{th} percentile value was 0.30 coils/cm (22). The UCI is traditionally categorised as hypocoiled/undercoiled (below 10^{th} percentile), normocoiled ($10\text{-}90^{th}$ percentile), hypercoiled/overcoiled (above 90^{th} percentile) (23,24).

The management of pregnancy might benefit from prenatal UCI determination. However, a comparative study (25) indicated that if the UCI was derived from a 10 cm segment rather than the entire length of the cord and there was an overestimation of over 25%, thus explaining why the evaluation of prenatal UCI is different from the evaluation of postnatal UCI (24,26). Furthermore, a significant correlation has not been found between UCI determined before delivery using ultrasound and after delivery by examination of the umbilical cord (27).

Patterns of coiling

Four patterns of umbilical coiling are reported, with the "Rope pattern" as the most common pattern, followed by the "Undulating pattern." The other two patterns are "Segmented" and "Linked" (28). A schematic representation of coiling patterns is shown in Figure 1.

Prenatal ultrasonography

Though technological and scientific advances are occurring rapidly in imaging and other fetal evaluation methods, significant constraints are noted in the available screening and diagnostic tests. Sometimes failure to identify fetal distress resulted in unwanted outcomes and other times, increased frequency of intervention for suspected abnormalities is found to be unnecessary. In this search for a reliable tool, antenatal identification of aberrant umbilical cord and umbilical coiling is the research target. Abnormal coiling or absent coiling has long been suggested to be associated with adverse outcomes of pregnancies, and if any are present, it would be important to identify the abnormality prenatally.

The umbilical cord is visible for the majority of the gestation and can be observed shortly after the fetal pole is seen. Due to the difficulty of measuring the umbilical cord with sonography during the first trimester, measurement errors may be significant. Given the reduced amniotic fluid content in the third trimester of pregnancy, it may be challenging to differentiate between umbilical cord coiling and torsion, and measurement errors may also arise (29). Second-trimester measurement is therefore favoured in many studies (30). However, even measurements taken in the second trimester have some disadvantages because it can be too early to detect fetal growth deficiencies (31).

The unbilical cord is divided roughly into three regions; the fetal region, linked to the fetal abdominal wall; the middle region which is free-floating; and the placental region that is attached to the placenta. For each of the three regions of the cord, adequate ultrasonographic visibility rates varied, with all three regions being seen clearly in only around 10% of cases (32). Added to that, attached ends do not accurately reflect cord coiling, while the free-floating segment is the area of the cord that is most susceptible to kinking and compression. Given these limitations, it is preferable to assess the middle region during the second trimester. If the visibility of the cord is adequate, three distinct segments or two to three consecutive segments in the middle region are determined and the mean UCI is calculated (32). However, studies have employed different measurement techniques leading to inter-observer bias, causing comparisons and drawing conclusions unreliable. Generalizing measurement guidelines will reduce inter-observer bias (33).

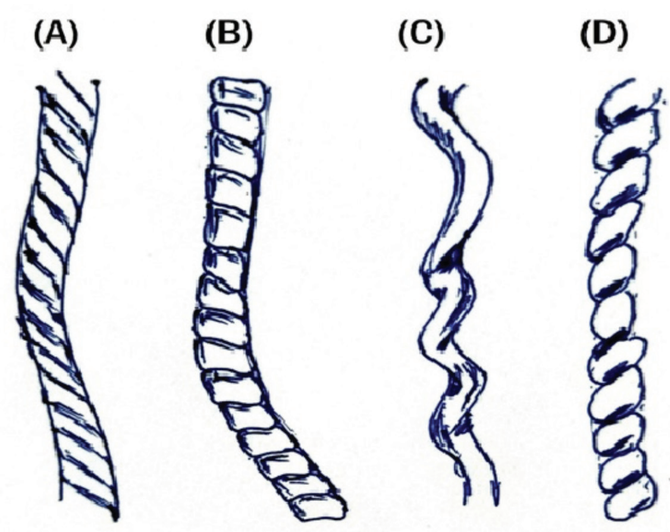

Figure 1. Schematic depiction of umbilical cord coiling patterns. (A) Rope, (B) segmented, (C) undulating, (D) linked

It is standard prctice to examine the umbilical cord's numerous characteristics during a routine second-trimester sonographic examination but the coiling index is not currently recommended (34). There aren't many research studies in this area that support the idea of using UCI for routine screening or even in special cases. Although UCI is indicated as a screening technique for adverse prenatal or antenatal events (35), it is unlikely to be beneficial as a screening tool for deviations from the expected in routine clinical practice, for example in preterm birth, due to its low predictive value (36). After studying 100 uncomplicated singleton pregnancies with no other comorbidities, Ma'ayeh et al. (27) also concluded the same. Mittal et al. (37) noted that UCI has a high negative predictive value for adverse perinatal outcomes. However, all of these studies were conducted with small sample sizes. According to the findings of another investigation, larger studies are necessary to validate the effective predictive ability of unbilical assessment and UCI in predicting the risk of small for gestational age (SGA) (26). Future fetal assessments in high-risk pregnancies may include the ultrasonographic evaluation of the umbilical cord and UCI, depending on the results of larger investigations.

Recently, a machine learning model for classifying images of the fetal umbilical cord using 2-D ultrasound Doppler has gained popularity (38). This development may lead to some progress in this area.

Factors contributing to umbilical coiling

There have been several hypotheses concerning the variables influencing umbilical cord coiling. Some supportive evidence was identified including that coiling patterns do not appear early in the gestation, which is supported by the observation that coiling is absent in early abortion specimens (39).

Some of the hypotheses about factors influencing umbilical coiling proposed in the later half of the 20th century include fetal movements (1), differential growth rates of umbilical vasculature (4), fetal hemodynamic forces (40), and the presence of snarls in the cord (14,32). Regrettably, no further research has focused on these postulates to date. In the early 21st century, the Roach muscle bundle hypothesis was proposed after conducting microscopic examinations of 251 umbilical cords. The Roach muscle, a small muscle bundle located directly next to the umbilical artery, was discovered in 101 umbilical cords, and the mean UCI was greater in cords with this muscle bundle (23). One interesting study published in 2019 showed that UCI is higher in female newborns compared to males after gestational age, gravidity and parity correction using multiple linear regression analysis (41). Conversely, Qin et al. (32) showed no significant relationship between gender and cord coiling. Once again, both studies had low sample size, and more studies with larger sample sizes must be performed to further investigate these intriguing findings.

There is generally limited evidence available, even concerning factors that are considered not to be associated with umbilical cord coiling. Such studies were on the thickness of the umbilical cord (42), parity and gravida (43), chorionicity, and zygosity (44,45). All these studies concluded no relation between the investigated factors and cord coiling. The age of the mother might be a confounding factor for the studies on parity, chorionicity, and zygosity (46). All these proposals put forward one or two variables, but recent studies show coiling is multifactorial with both environmental and genetic involvement (46).

Umbilical blood vessel flow characteristics and umbilical coiling

When pressures are monitored concurrently, the pulse pressures of the umbilical arteries and umbilical vein are 180° out of phase. During pulsations, arteries lengthen and the diameter narrows, and this mechanism causes the widening of the vein's diameter and experiences a relative drop in pressure. The venous blood is pumped forward in this manner. The greater the number of coils, the greater the impact of the arteries' pressure pulses on the vein and, thus the greater the increase in venous flow (47). Degani et al. (24) also discovered a linear relationship between umbilical vein flow and UCI ($r=0.59$, $p=0.001$), but no correlation was noted between Doppler characteristics in the umbilical arteries and UCI. However, a three-dimensional computer simulation tool for blood flow in the umbilical artery revealed that increased coiling necessitates a considerable rise in pressure gradient to keep a given blood flow because of the impact of coiling on the streamlining of flow and wall shear stresses (48). Yet another cross-sectional study conducted in Japan showed that umbilical artery and venous blood flow are not affected by UCI at 11-13 weeks of gestation (49). Further standardized studies might answer this disparity and help in reaching firm conclusions.

As mentioned earlier, the cord's resilience to kinking and compression may be increased by the coils, but the reverse was observed under a strong encircling force. Georgiou et al. (50) conducted an experiment with standardized tight encirclement pressure to measure venous perfusion and noted an inverse correlation between UCI and the minimal weight needed to plug venous perfusion. One more interesting characteristic is that the variations in blood flow parameters between the hyper-, hypo-, and normo-coiled umbilical cords were minimal and statistically insignificant (31). However, potential clinical consequences are unclear and a conclusion about Doppler characteristics cannot be reached with these small studies and no subsequent conclusive studies.

Review and discussion

An all-language literature search was conducted on Medline for the period 1970 to 2023. The following search terms were used: umbilical cord; umbilical coiling; coiling index; abnormal coiling; perinatal outcomes, and cross-referencing yielded further information.

Abnormal coiling (under-, over-, and non-coiling) is associated with an increased risk of several unfavourable perinatal events. Set in early gestation, abnormal coiling develops into a chronic state that can have both acute and chronic implications for the fetus. Several studies have been performed showing these associations.

Maternal age and gravida

Although advanced maternal age is known to be associated with adverse pregnancy outcomes (51), studies have shown that abnormal coiling, either hypocoiling or hypercoiling, was not significantly associated with maternal age (52,53). Similarly, the gravida of the mother had no effect on the likelihood of abnormal coiling (36,43). These findings are consistently reported with no contrary findings reported in the literature we explored.

Gestational diabetes mellitus

Most studies conducted in this field showed a significant association between gestational diabetes mellitus (GDM) and abnormal coiling (54-56), with hypocoiling as the most abnormal pattern found (57). However, some studies showed no significant association between GDM and occurrence of abnormal coiling (58). This disagreement between studies could be attributed to subgroup analysis in their evaluations, as well as population selection.

Pre-eclampsia

Research showed a significant association between pre-eclampsia with both hypocoiled (54) and uncoiled (an extreme form of hypocoiled) cords (55,59). Due to the elastic properties of the coiled umbilical cord, it can withstand outside forces that could disrupt the vascular flow. In addition, a coiled cord is more resistant to compression, snarling torsion, and stretch than the hypocoiled or uncoiled cords (59,60). This could explain the link between hypocoiling and pre-eclampsia.

Pre-eclampsia is linked to adverse fetal outcomes, such as preterm birth, intrauterine growth retardation (IUGR), low birth weight (LBW), and fetal and neonatal death, and later chronic diseases (61), which independently showed associations with umbilical cord coiling. A study showed an association between excessive coiling and fetoplacental vascular resistance and put forward hypercoiling as a risk factor for preeclampsia (62). The disparity between the findings of these two studies show the large amount of missing information regarding this topic and yet to be explained. This will necessitate multiple future studies.

Abruption (abruptio placentae)

Abruption was documented significantly more often in cases with hypocoiled umbilical cords than in normo-coiled and hypercoiled cords (35,54). The close association between abruption and preeclampsia is most probably the reason for this finding (54).

Maternal thyroid disease

Maternal thyroid disease (hypothyroidism and hyperthyroidism) and abnormal umbilical coiling had no significant association, according to a study done in 2018 (57). However, with only one study conducted so far, no robust conclusions can yet be drawn.

Maternal iron status

Following a rise in erythrocyte count in the placental villous circulation, de Laat et al. (63) discovered that increased coiling was connected to prolonged fetal hypoxia/ischemia. Deficient maternal iron status (lower serum ferritin and lower total body iron values) might cause fetal anaemia and, subsequently, hypoxia, which means that hypercoiling may have relevance in mothers with abnormal iron status. Steinl et al. (46) also reported that hypercoiling was associated with lower maternal iron status.

UCI scores and cord blood transferrin saturation were found to be positively correlated by Namli Kalem et al. (64), although there was no connection between UCI and maternal ferritin. However, this difference was due to the use of linear correlation analysis instead of using categories of UCI because the aim was to investigate factors affecting umbilical coiling. The connection between hypercoiling and iron status needs to be explained in more comprehensive investigations with larger sample numbers.

Vascular endothelial growth factor A

Vascular endothelial growth factor A (VEGFA), an angiogenesis regulator, is necessary during the prenatal period for trophoblast proliferation, endothelial cell migration, embryonic vasculature development, and maternal and fetal blood vessel enlargement in the uterus, vasodilation, and angiogenesis. We found only one study investigating the association between VEGFA and abnormal coiling and this concluded that abnormal coiling patterns appear to be related to the down-regulation of VEGFA (65).

Oligohydramnios and polyhydramnios

Oligohydramnios has been significantly associated with hypocoiling (37,54) whereas polyhydramnios was significantly associated with hypercoiling (54). Edmond's hypothesis (1) is the answer to this observation. This hypothesis suggests that the rotating movement provided to the embryo causes the twist of the umbilical cord, and therefore the larger the fluid amnii, the greater the rotary movement of the fetus, and hence the coiling. The opposite is true for oligohydramnios. However, a large number of studies are needed to provide conclusive evidence about this association. Currently there are a limited number of studies with small samples and thus it is not possible to comment on these associations with any certainty.

Fetal heart rate variations

Studies have consistently shown a significant correlation between fetal heart rate abnormalities and both hypercoiled and hypocoiled umbilical cords (37,54,66,67). Abnormal coiling being less flexible and more prone to torsion and kinking, means these are less able to tolerate the stress of labor compared to normocoiled cords (67). As stated in the latter part of this article, this observation might also explain increased interventional deliveries in abnormal coiling, as interventional deliveries are used for fetuses with heart rate abnormalities.

Small for gestational age and intrauterine growth restriction

SGA is defined as a birth weight of less than the 10th percentile for gestational age while IUGR is defined as a rate of fetal growth that is below normal. Abnormal coiling was consistent with both SGA and IUGR babies (52,68,69), with most studies supporting this.

Studies such as Machin et al. (60) and Strong et al. (67) showed that hypocoiling was associated with SGA and IUGR and concluded that hypocoiling eventually reduces fetoplacental circulation, which limits growth. This association was also noted by Chitra et al. (54). However, studies such as that of Ezimokhai et al. (55) and others reported an association between hypercoiling and both SGA and IUGR (43,50,53). This fact that both under- and over-coiling of the umbilical cord may be associated with both SGA and IUGR is not yet explained. Irrespective of the type of abnormal coiling, it is not wrong to say that abnormal coiling is significantly associated with SGA and IUGR.

Ponderal index

The ponderal score or index (PI) is calculated as weight (kg) divided by cubed height (m^3). As abnormal coiling is linked with fetal growth restriction, the PI is altered in abnormal coiling (43). However, Gupta et al. (59) studied around 100 cords and concluded no association between PI and abnormal coiling. We expect this might be due to the reason that both variables in the calculation of the PI are affected in the same direction by abnormal coiling and PI is a ratio of these two variables.

Intrauterine death and abortion

Only a few studies have been done in this area, but studies consistently showed a notable association between hypercoiling and intrauterine death (IUD) and abortions (70,71). Past research suggested that constriction and torsion occur after fetal death as a result of the maceration process. However, there is a widespread assumption that hypercoiling interrupts fetal-placental circulation and leads to undesirable consequences (71). Furthermore, a similar association is seen between non-coiled umbilical cords and an increased risk for perinatal morbidity and mortality (67). This might be because of the configuration, as coiling is structurally more resistant to external pressures and this advantage is lost in non-coiled cords.

Fetal presentation

There is little data in the literature to review the relationship between the presentation of fetuses and coiling. Ochshorn et al. (72) claimed the first report on this association and reported that fetuses in the breech presentation have noticeably shorter and less coiled cords and lower mean UCI, while no variation was observed in vertex presentation. The precise cause or causes of these differences are as yet unknown.

Mode of delivery

Umbilical cords with UCI values $>90^{th}$ percentile and $<10^{th}$ percentile were significantly associated with lower segment caesarean section than umbilical cords with UCI between 90^{th} and 10^{th} percentiles (37,43,54). Though such an association was discovered in the majority of studies, the underlying cause is not explained in the literature. However, UCI may not be directly related to the mode of delivery but to adverse clinical outcomes, which influence the mode of delivery.

Preterm birth

Preterm birth is a live birth that occurs before 37 completed weeks of pregnancy. Similar to SGA and IUGR, abnormal coiling was significantly associated with preterm birth (36,69,73). The majority of the studies showed that hypocoiling was significantly linked to preterm birth (35,37,54,67), but these studies couldn't provide a convincing reason for this finding. Rana et al. (74) and de Laat et al. (63) revealed a connection between preterm birth and hypercoiling. According to these findings, hypercoiling is an adaptive response to fetal hemodynamic alterations that produce premature labor when a particular threshold is crossed.

In addition, the presence of meconium was found to be more strongly associated with abnormal coiling than with normal coiling of umbilical cords (35,43,55,59,68). However, none of the studies provided a specific explanation for the finding. A meta-analysis and a sequential analysis performed in 2019 supported the findings of these previous studies (69).

Birth weight

Predanic and Perni (42) showed that antenatal UCI is a good predictor of neonatal birth weight. So, changes in coiling patterns are obvious in LBW (birth weight <2.5 kg) cases (54). The literature shows a consistent association between LBW and hypocoiling (35) and hypercoiling (74,75). Mittal et al. (37) suggested that this association could be due to higher preterm deliveries in the hypocoiled group and a higher count of babies born with SGA in the hypercoiled group.

APGAR scores

de Laat et al. (53) and other studies found that low APGAR scores at 1 minute and 5 minutes are significantly associated with UCI $<10^{th}$ percentile compared to normocoiled cords (43,59,68,73). Sharma et al. (35) noted a prominent association between hypercoiling and low APGAR scores at 1 minute and 5 minutes. The association of low APGAR scores with hypocoiling was explained by Georgiou et al. (50) as an inverse relationship was noted between the UCI and the minimum load required to plug venous perfusion, implying that hypocoiling may contribute to compression, as well as kinking, resulting in low APGAR scores. Nevertheless, the authors provided no explanation for the link between low APGAR scores and hypercoiling. Based on these findings, we can conclude that low APGAR scores and abnormal coiling have an association (54,69) and that with larger studies, cause and effect may become clearer.

Neonatal intensive care unit admissions

Babies admitted to the neonatal intensive care unit (NICU) showed a significant association with abnormal coiling, especially with hypocoiling (43,53) and hypercoiling (73) and even with non-coiling (67). However, in one study by Devaru and Thusoo (68) there was no statistical significance in the association between NICU admission and coiling. We believe that the discrepancies between studies are primarily due to different NICU admission criteria, comorbidities, and available local resources.

Conclusion

The umbilical cord has garnered little attention, despite its critical involvement as a connection between placental and fetal circulation. The cord coiling index is preferably determined in the second trimester by observing the middle region of the cord. Studies show that maternal age and gravida were not associated with abnormal coiling. In contrast, a significant association was seen with SGA, IUGR, preterm birth, LBW, low PI, IUD, low APGAR scores, fetal heart rate variations, fetal presentation, and increased instrumental deliveries. There were also significant associations with GDM, preeclampsia, and abruption. Limited research has suggested significant associations with maternal iron status, oligohydramnios and polyhydramnios, and down-regulation of VEGFA, but no association with thyroid disease. Several studies have linked abnormal coiling to abnormal perinatal outcomes, but there are differences in hyper- and hypo-coiling which need to be addressed. The umbilical cord coiling characteristic may not be the only significant factor when considering umbilical cord anatomy in terms of fetal outcome. It is unclear if aberrant coiling is the origin of pathology or one of its consequences (cause and effect) and how much clinical significance it has.

The small sample sizes were a major limitation in most of the studies conducted so far and this limitation can be countered by performing large, multicentric studies. Furthermore, interrelationships between various umbilical cord characteristics require further focus in addition to studies on the association between coiling and clinical outcomes.

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