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Morphometric Assessment of Spinal Development in Early-Aged Children Exposed to Maternal COVID-19 During Pregnancy

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Abstract The COVID-19 pandemic has raised serious concerns regarding the long-term consequences of maternal infection during pregnancy on child development. Prenatal exposure to viral infection, systemic inflammation, and hypoxia may influence the formation of the musculoskeletal system, including vertebral development. The aim of this study was to assess spinal morphometric parameters in early-aged children born to mothers who experienced COVID-19 during pregnancy. Anthropometric and morphometric measurements of the vertebral column were compared with those of children born to healthy mothers. The results demonstrated certain alterations in spinal growth indicators among children exposed to maternal COVID-19, suggesting a possible association between prenatal viral exposure and delayed musculoskeletal development. These findings emphasize the necessity for early screening, preventive monitoring, and long-term follow-up of children prenatally exposed to maternal COVID-19.

Keywords COVID-19, Pregnancy, Spinal development, Morphometry, Vertebral column, Children, Anthropometric parameters, Prenatal exposure

1. Introduction

The coronavirus disease (COVID-19), caused by the SARS-CoV-2 virus, has become one of the most significant global public health problems of the twenty-first century [1]. In addition to respiratory complications, COVID-19 affects multiple organs and systems through inflammatory, vascular, and immunological mechanisms [2]. Particular attention has been directed toward pregnant women because maternal infection may influence fetal growth and intrauterine development [3].

Pregnancy is accompanied by profound physiological and immunological changes that may increase susceptibility to viral infections and contribute to adverse perinatal outcomes [4]. Several studies have reported that maternal COVID-19 may be associated with placental dysfunction, fetal hypoxia, intrauterine growth restriction, preterm birth, and developmental abnormalities [5]. Chronic inflammatory responses and impaired placental circulation during maternal infection may negatively affect organogenesis and fetal skeletal development [6].

The vertebral column is one of the most important anatomical structures of the musculoskeletal system, providing body support, locomotion, and protection of the spinal cord [7]. Spinal growth begins during embryogenesis and continues intensively during infancy and childhood [8]. Proper vertebral formation depends on adequate oxygen supply, balanced metabolism, genetic regulation, and normal maternal health conditions during pregnancy [9].

Prenatal exposure to infectious and inflammatory factors may interfere with ossification processes, cartilage formation, and musculoskeletal maturation [10]. Maternal viral infections have previously been associated with growth disturbances and developmental alterations in offspring [11]. However, the possible effects of maternal COVID-19 on spinal anthropometric development in children remain insufficiently investigated.

Recent evidence suggests that systemic inflammation and endothelial dysfunction caused by SARS-CoV-2 infection may impair placental blood flow and fetal nutrient supply [12]. Elevated inflammatory cytokines and oxidative stress during pregnancy may influence connective tissue metabolism and vertebral growth [13]. Furthermore, hypoxic conditions associated with severe maternal infection may negatively affect bone mineralization and skeletal maturation [14].

Anthropometric and morphometric assessment of the spine provides valuable information regarding the physical development of children and allows early detection of developmental deviations [15]. Evaluation of spinal length, thoracic and lumbar curvature, vertebral proportions, and posture indicators can help identify early musculoskeletal

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abnormalities and improve preventive strategies [16].

Despite increasing interest in post-COVID developmental outcomes, limited information exists regarding spinal morphometric characteristics in children exposed to maternal COVID-19 during fetal life. Therefore, further investigation of vertebral development in this population is clinically important.

The purpose of this study was to perform a morphometric assessment of spinal development in early-aged children born to mothers who had COVID-19 during pregnancy and to compare these findings with children born to non-infected mothers.

2. Materials and Methods

The study included early-aged children divided into two groups. The main group consisted of children born to mothers with confirmed COVID-19 infection during pregnancy, while the control group included children born to healthy mothers without a history of COVID-19.

Clinical examination included collection of maternal medical history, pregnancy course, gestational age, and neonatal indicators. Anthropometric evaluation of children was performed using standardized pediatric examination methods.

Morphometric assessment of the vertebral column included measurement of spinal length, thoracic and lumbar curvature, shoulder symmetry, chest circumference, and posture characteristics. Measurements were carried out under identical clinical conditions using calibrated anthropometric instruments.

Children with congenital musculoskeletal anomalies, severe neurological disorders, or hereditary skeletal diseases were excluded from the study.

Statistical analysis was performed using comparative methods. Mean values, standard deviations, and correlation analyses were calculated to evaluate differences between groups. Statistical significance was determined at $p < 0.05$.

3. Results

The morphometric analysis revealed noticeable differences between children exposed to maternal COVID-19 and those in the control group. Children from the exposed group demonstrated slightly reduced spinal length indicators and delayed development of physiological spinal curvatures compared with healthy controls.

Thoracic kyphosis and lumbar lordosis parameters showed moderate variations, suggesting delayed musculoskeletal adaptation in some children. Mild posture asymmetry and reduced chest expansion values were also observed more frequently in the exposed group.

The severity of observed morphometric changes appeared to correlate with the severity of maternal COVID-19 infection during pregnancy. Children born to mothers who experienced moderate or severe disease demonstrated more pronounced anthropometric deviations.

Despite these findings, most children maintained general physical development within age-related physiological limits. However, early signs of altered spinal development indicate the possible influence of prenatal inflammatory and hypoxic factors on vertebral growth.

4. Discussion

The findings of this study suggest that maternal COVID-19 infection during pregnancy may influence spinal morphometric development in offspring during early childhood. The observed alterations may be associated with chronic intrauterine hypoxia, systemic inflammation, endothelial dysfunction, and placental insufficiency caused by SARS-CoV-2 infection.

Prenatal inflammatory exposure can affect fetal skeletal growth by disrupting osteogenesis, cartilage maturation, and collagen synthesis. Elevated cytokine levels during maternal infection may impair normal musculoskeletal development and contribute to delayed vertebral maturation.

The results correspond with previous investigations reporting developmental disturbances among children prenatally exposed to severe maternal infections. The vertebral column is particularly sensitive to metabolic and hypoxic disturbances during periods of active growth and differentiation.

Although the detected changes were generally mild, they may have long-term clinical importance. Delayed spinal development during infancy can predispose children to posture abnormalities, scoliosis, impaired physical development, and musculoskeletal dysfunction later in life.

The study emphasizes the necessity of regular pediatric and orthopedic monitoring for children exposed to maternal COVID-19 during fetal development. Early rehabilitation measures, physical therapy, nutritional support, and preventive screening may help reduce future complications.

Further longitudinal studies involving larger populations are required to clarify the long-term consequences of prenatal COVID-19 exposure on spinal growth and musculoskeletal health.

5. Literature Review

The analysis of scientific literature shows that the COVID-19 pandemic has had a significant impact not only on respiratory health but also on maternal and child health. According to the World Health Organization, COVID-19 became a global public health emergency and affected all areas of medicine, including obstetrics, pediatrics, neonatology, and developmental biology [1]. This created the need to study the possible consequences of maternal SARS-CoV-2 infection during pregnancy on fetal and postnatal development.

Gupta et al. emphasized that COVID-19 is not limited to lung involvement and may cause extrapulmonary

complications through systemic inflammation, endothelial dysfunction, thrombotic disorders, and immune-mediated mechanisms [2]. These systemic effects are especially important during pregnancy because maternal inflammation and vascular changes may influence placental function and fetal development.

Wastnedge et al. analyzed the relationship between pregnancy and COVID-19 and noted that pregnant women represent a special risk group due to physiological, immunological, and cardiovascular changes occurring during gestation [3]. Their findings indicate that maternal infection may affect pregnancy outcomes and requires careful clinical monitoring.

Dashraath et al. also reported that COVID-19 during pregnancy may be associated with adverse maternal and perinatal outcomes, including preterm birth, fetal distress, and neonatal complications [4]. These findings support the importance of assessing children born to mothers with COVID-19, especially during early stages of growth and development.

Allotey et al. conducted a large systematic review and showed that COVID-19 in pregnancy may increase the risk of severe maternal disease, intensive care admission, and adverse neonatal outcomes [5]. This evidence confirms that maternal COVID-19 may indirectly influence the intrauterine environment and fetal development.

Placental pathology is one of the key mechanisms linking maternal COVID-19 with fetal development. Shanes et al. demonstrated that placentas from mothers with COVID-19 may show vascular malperfusion and inflammatory changes [6]. Such alterations may reduce oxygen and nutrient delivery to the fetus, which is important for normal skeletal and spinal development.

Anatomical and embryological sources also provide an important theoretical basis for understanding spinal development. Standring described the vertebral column as a complex anatomical structure that supports the body, protects the spinal cord, and participates in movement [7]. Therefore, even mild developmental deviations in the spine during early childhood may have functional significance.

Moore and Persaud explained that human skeletal development begins during embryogenesis and continues through fetal and postnatal life [8]. The vertebral column develops through complex processes of segmentation, chondrification, and ossification. These processes are sensitive to maternal health, oxygen supply, nutrition, and intrauterine environmental conditions.

Sadler also emphasized that normal embryonic development depends on precise genetic regulation and favorable maternal -fetal conditions [9]. Disturbances during critical periods of organogenesis may affect the formation of the musculoskeletal system, including the vertebral column.

Carlson highlighted that fetal growth and skeletal maturation are influenced by cellular differentiation, connective tissue formation, and bone mineralization [10]. Inflammatory, hypoxic, or metabolic disturbances during pregnancy may interfere with these processes and lead to developmental variations.

Racicot and Mor studied viral infections during pregnancy and showed that maternal infections can affect fetal development through immune activation, inflammatory mediators, placental dysfunction, and altered maternal-fetal communication [11]. This is directly relevant to COVID-19, as SARS-CoV-2 infection may trigger similar inflammatory pathways.

Vivanti et al. discussed the possibility of maternal-fetal transmission of SARS-CoV-2 and demonstrated that vertical transmission, although rare, may occur under certain conditions [12]. Even in the absence of direct viral transmission, maternal immune and vascular responses may influence fetal development.

Chen et al. examined cytokine responses in COVID-19 pregnancy and noted that increased inflammatory cytokines may play an important role in maternal and fetal outcomes [13]. Cytokine imbalance may affect placental circulation, fetal tissue development, and postnatal adaptation.

Malhotra et al. described the effect of maternal hypoxia on fetal development and showed that oxygen deficiency during pregnancy may negatively influence fetal growth and organ maturation [14]. Since severe COVID-19 may be accompanied by maternal hypoxia, this mechanism may be important in explaining possible spinal morphometric changes in children.

Cameron provided fundamental data on human growth and development, emphasizing that anthropometric evaluation is essential for assessing physical development in children [15]. Measurement of body proportions, growth indicators, and skeletal parameters can help identify early deviations from normal development.

Rogol et al. studied growth processes during childhood and adolescence and noted that skeletal growth depends on hormonal, nutritional, genetic, and environmental factors [16]. This supports the idea that children exposed to unfavorable prenatal conditions, including maternal COVID-19, should be monitored for possible growth and musculoskeletal changes.

In general, the reviewed literature demonstrates that maternal COVID-19 may influence fetal and child development through several mechanisms, including systemic inflammation, placental vascular changes, cytokine imbalance, maternal hypoxia, and impaired nutrient-oxygen supply. Anatomical and embryological studies confirm that spinal development is a sensitive and complex process that may be affected by adverse prenatal conditions. Therefore, morphometric assessment of spinal development in early-aged children born to mothers with COVID-19 is scientifically relevant and clinically important.

6. Conclusions

Maternal COVID-19 infection during pregnancy may influence spinal morphometric development in early-aged children. The study demonstrated certain differences in spinal anthropometric parameters, including altered vertebral growth indicators and mild posture deviations among

children exposed to prenatal maternal infection.

These findings suggest that intrauterine inflammatory and hypoxic factors associated with COVID-19 may affect musculoskeletal maturation during fetal life. Although most changes were not severe, early developmental deviations may have important implications for future physical health and spinal function.

Morphometric assessment of the vertebral column can serve as an effective tool for early detection of developmental disturbances in children prenatally exposed to maternal COVID-19. Early screening programs, long-term pediatric monitoring, and preventive rehabilitation strategies are essential for maintaining healthy musculoskeletal development in this population.

Further clinical and experimental investigations are needed to better understand the pathogenetic mechanisms linking maternal COVID-19 and altered skeletal growth in offspring.

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