

Morphological and Functional Features of Fetal Internal Organs in Forensic Practice

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Abstract A forensic medical evaluation of the morphofunctional characteristics of fetal internal organs was conducted with the aim of improving the accuracy of gestational age determination based on a comprehensive analysis of forensic medical protocol data. The study material comprised 65 forensic medical reports (forensic examination protocols) of fetuses referred for expert evaluation due to intrauterine fetal death, stillbirth, and neonatal death of unknown etiology microscopic assessment included analysis of the degree of pulmonary alveolar differentiation, the intensity of hepatic hematopoiesis, the development of corticomedullary differentiation in the kidneys, the structural organization of the myocardium, and the degree of thymic maturity. Gestational age was determined by correlating the morphological characteristics of internal organs with generally accepted embryological and morphometric criteria of intrauterine development.

Keywords Forensic medical examination, Gestational age, Fetus, Morphofunctional characteristics, Organogenesis, Histological diagnosis

1. Introduction

Determining the gestational age of the fetus is a key task in forensic medical examinations during the investigation of perinatal and intrauterine deaths, as well as in cases of criminal abortions, intrauterine death, and neonatal deaths of unknown etiology [1,2,3]. Accurate verification of the gestational age is essential for the correct legal classification of the case, establishing fetal viability, assessing the timeliness and adequacy of medical care, and for the differential diagnosis of antenatal and intrapartum deaths. Modern forensic practice demonstrates that traditional anthropometric indicators (weight, fetal length, head circumference) do not always reflect the actual gestational age, especially in cases of intrauterine growth restriction, chronic placental insufficiency, intrauterine hypoxia, and congenital pathology [4,5,6]. Under these circumstances, the role of morphofunctional criteria of internal organs, which more objectively reflect the degree of fetal maturity and the stages of organogenesis, increases. Morphological assessment of the degree of parenchymal organ differentiation, the maturity of the alveolar apparatus of the lungs, the corticomedullary differentiation of the kidneys, and the development of the thymus, adrenal glands, and liver allows for increased accuracy in gestational age determination, especially at the borderline stages of fetal

viability [7,8]. A comprehensive analysis of macroscopic, histological, and, where necessary, immunohistochemical features forms a scientifically sound algorithm for forensic diagnostics. In the future, standardization of morphofunctional criteria for internal organs and their implementation in forensic practice will improve the objectivity of expert opinions, reduce diagnostic discrepancies, and ensure a unified interdisciplinary approach to assessing fetal gestational age, which has important medical, legal, and social implications.

Objectives

The aim of this study was a forensic medical assessment of the morphofunctional characteristics of the internal organs of the fetus in order to improve the accuracy of determining gestational age based on a comprehensive analysis of forensic medical records.

2. Materials and Methods

The study was based on the analysis of 65 forensic medical examination reports of fetuses submitted for expert evaluation due to intrauterine fetal death, stillbirth, or neonatal death of unknown etiology. All examinations were conducted in accordance with standard forensic medical protocols. In each case, a complete forensic autopsy was performed, including external examination and anthropometric assessment (body weight, crown–heel length, head circumference, and chest circumference). The morphofunctional condition of internal organs, particularly the lungs, liver, kidneys, heart, thymus, spleen, and adrenal

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glands, was evaluated.

Tissue samples were fixed in 10% neutral buffered formalin and processed using routine histological techniques with hematoxylin and eosin (H&E) staining. Microscopic evaluation focused on the degree of pulmonary alveolar differentiation, hepatic hematopoietic activity, corticomedullary differentiation of the kidneys, myocardial organization, and maturity of lymphoid and endocrine organs. Gestational age was determined by correlating morphofunctional findings with established embryological and morphometric criteria. Cases were divided into two groups: second trimester (22–27 weeks) and third trimester (≥ 28 weeks). Statistical analysis was performed using Microsoft Excel, applying the Pearson χ^2 test and Mann–Whitney U test. Differences were considered significant at $p < 0.05$.

3. Results and Discussion

Analysis of the examined cases revealed that morphofunctional characteristics of fetal internal organs provide reliable indicators of gestational maturity. Microscopic evaluation demonstrated consistent associations between the degree of organ differentiation and gestational age, irrespective of fetal anthropometric parameters. In the kidneys, marked variability in corticomedullary differentiation was observed. The predominance of a wide nephrogenic zone and the presence of immature glomeruli were characteristic of earlier gestational stages, even in fetuses with relatively higher body weight. These findings highlight the limited diagnostic value of anthropometric data alone and emphasize the importance of renal histological maturity as an indicator of gestational age. Pulmonary tissue exhibited gestational age–dependent differences in the development of the alveolar apparatus. In earlier stages, the lungs were characterized by an immature alveolar structure with poorly differentiated air spaces, whereas progressive gestational advancement was associated with increased alveolar complexity and the appearance of secondary alveoli. These changes reflect functional maturation of the respiratory system and are critical for assessing fetal viability in forensic practice.

Hepatic morphology demonstrated a gradual decline in hematopoietic activity with increasing gestational age. Pronounced extramedullary hematopoiesis was a typical finding in less mature fetuses, while its reduction indicated advancing fetal development. Similar gestational trends were observed in the myocardium, where increasing structural organization and fiber alignment corresponded to later stages of intrauterine maturation. The thymus and adrenal glands showed distinct morphofunctional patterns related to gestational age. Insufficient corticomedullary differentiation of the thymus and predominance of the fetal zone in the adrenal glands were indicative of earlier developmental stages. In contrast, advanced gestation was associated with thymic structural maturation, reflecting functional development of the fetal immune system, and a relative reduction of the fetal adrenal zone.

Comparative analysis between fetuses in the second and third trimesters revealed clear differences in the degree of morphofunctional maturity of internal organs. The second trimester was characterized by features of structural immaturity, including persistent nephrogenic zones in the kidneys, active hepatic hematopoiesis, and incomplete alveolar development. In the third trimester, organ morphology reflected functional readiness, with mature pulmonary architecture, reduced nephrogenesis, decreased hematopoietic activity in the liver, and advanced myocardial organization.

Overall, the results demonstrate that a comprehensive morphofunctional assessment of fetal internal organs possesses high discriminatory capacity for distinguishing between gestational stages.

Table 1. Frequency of detection of diagnostically significant morphological features (n = 65)

Morphological feature	Abs. number	%
Immature alveolar apparatus	29	44,6
Pronounced hepatopoiesis	34	52,3
Preservation of the nephrogenic zone	31	47,7
Hypoplasia of the lymphoid structures of the spleen	18	27,7

A comprehensive morphofunctional assessment of fetal internal organs is an objective and reproducible method for determining gestational age, superior in diagnostic value to the use of isolated anthropometric parameters. The introduction of standardized morphological criteria will improve the quality of forensic medical reports in the future. Statistical processing of the results was performed using Microsoft Excel. All cases were divided into two comparative groups based on gestational age: second trimester (22–27 weeks of gestation) and third trimester (≥ 28 weeks of gestation). The Pearson χ^2 test was used to distinguish between features and the presence or absence of morphological maturity criteria. The nonparametric Mann–Whitney U test was used for quantitative and ordinal indicators of morphological maturity. Results are presented as absolute and relative values, median, and interquartile range. Differences were considered statistically significant at $p < 0.05$.

Microscopic examination of fetal kidney tissue reveals features consistent with gestational immaturity and sensitivity to hypoxic-ischemic injury. The renal parenchyma is characterized by an incomplete corticomedullary differentiation. Numerous immature glomeruli are observed, predominantly at the cortical level, with poorly developed capillary loops and widened Bowman's spaces (fig №1-2). The glomerular tufts are often collapsed or hypoplastic. Renal tubules demonstrate varying degrees of dystrophic changes. The epithelium of proximal and distal tubules shows cytoplasmic vacuolization, swelling, and focal desquamation into the tubular lumen. In cases associated with intrauterine hypoxia, areas of coagulative necrosis of tubular epithelium may be identified. The interstitial tissue is moderately edematous, with dilated, congested capillaries and occasional focal

hemorrhages. Inflammatory infiltration is usually absent or minimal, reflecting the non-infectious nature of the injury. Functionally, these changes indicate impaired fetal renal filtration and tubular transport, which are highly vulnerable to placental insufficiency and acute hypoxic conditions. Histological structure of the fetal lung corresponds to the canalicular or saccular stage of development, depending on gestational age. The lung parenchyma consists of immature alveolar sacs separated by thickened interalveolar septa rich in mesenchymal cells and capillaries. Alveolar spaces are irregular, often partially collapsed or overdistended. The interalveolar septa are edematous and congested, with marked capillary hyperemia and, in some cases, erythrocyte extravasation. The alveolar lumens may contain proteinaceous eosinophilic material, desquamated epithelial cells, and occasional macrophages. Hyaline membrane formation is generally absent or poorly developed, distinguishing fetal hypoxic injury from postnatal respiratory distress syndrome. Bronchioles exhibit preserved epithelial lining but show peribronchiolar edema and vascular congestion. These morphological features reflect functional respiratory immaturity and impaired gas exchange capacity, particularly in cases of antenatal hypoxia or acute placental circulatory failure.

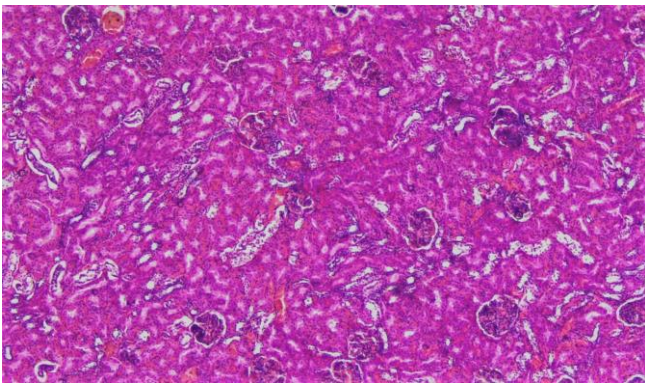


Figure 1. The criteria for immaturity of fetal kidney tissue are shown; there are embryonic glomeruli at 24 weeks, surrounded by heme-eosin, magnification: 10x10

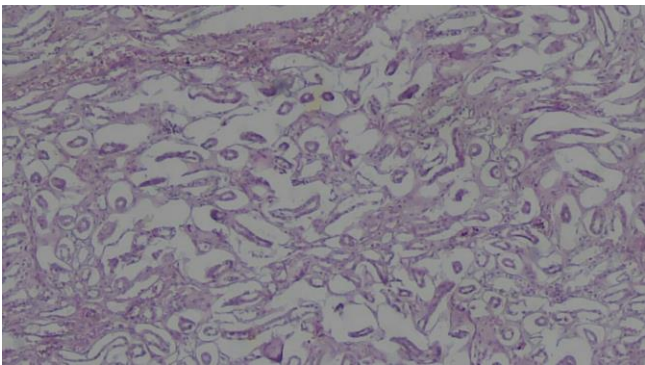


Figure 2. Immaturity of nephrons in a deceased fetus at 28 weeks of gestational age, surrounded by heme-eosin, magnification: 10x10

In Fig. 3 of the lung tissue, the alveolar structure is largely preserved; however, the interalveolar septa are unevenly thickened due to pronounced edema, vascular congestion, and cellular infiltration. Inflammatory cell accumulations,

primarily lymphocytes and neutrophils, are observed in the septa and peribronchial zone. Some alveoli are sharply dilated, their lumens are optically empty or contain fine-grained eosinophilic exudate. Desquamated alveolocytes and isolated inflammatory cells are detected in individual alveoli. Signs of alveolar emphysematous hyperdistension are observed in some places. The bronchiole has a preserved epithelial lining, but its wall is thickened and infiltrated with inflammatory cells; the peribronchial connective tissue shows pronounced edema and vascular disorders. The vessels of the microcirculatory bed are dilated, full-blooded, in places with signs of stasis.

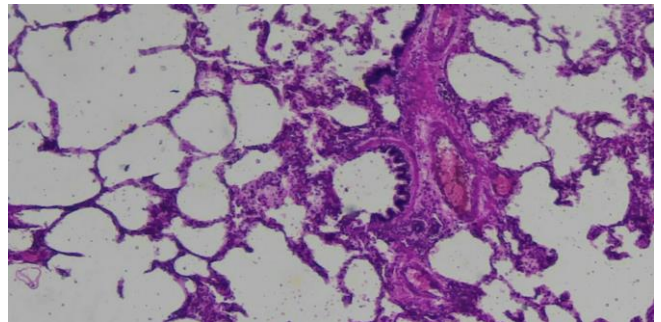


Figure 3. Lung. The alveolar structure is largely preserved in the lung tissue; however, the interalveolar septa are unevenly thickened due to severe edema, vascular congestion, and cellular infiltration. Heme-eosin staining. 10x10

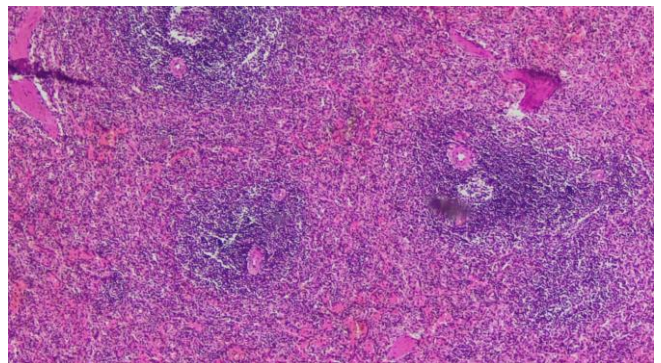


Figure 4. The spleen contains secondary germinal centers of lymphoid follicles and vascular hyalinosis. Heme-eosin staining. 10x10

The fetal spleen demonstrates structural immaturity with predominance of red pulp elements. White pulp is poorly differentiated or represented by small, indistinct lymphoid aggregates without clear periarteriolar lymphoid sheaths. This reflects the incomplete development of the fetal immune system. The red pulp shows pronounced vascular congestion, with dilated sinusoids filled with erythrocytes. Extramedullary hematopoiesis is a prominent finding, represented by clusters of erythroid and myeloid precursor cells. In hypoxic conditions, focal hemorrhages and stromal edema may be observed. No significant inflammatory infiltrates are typically present. Functionally, these findings indicate a compensatory hematopoietic response and circulatory redistribution, commonly seen in fetuses subjected to chronic intrauterine stress. The spleen contains secondary germinal centers of lymphoid follicles and vascular hyalinosis.

4. Conclusions

The present study demonstrates that a comprehensive morphofunctional assessment of fetal internal organs is a highly informative and reliable approach for determining gestational age in forensic medical practice. The results confirm that morphological criteria of organ maturity provide more objective and accurate indicators of fetal development than isolated anthropometric parameters, particularly in cases complicated by intrauterine growth restriction, placental insufficiency, or hypoxic conditions. Distinct gestational age-dependent patterns were identified in the lungs, kidneys, liver, heart, thymus, spleen, and adrenal glands. Renal corticomedullary differentiation, pulmonary alveolar maturation, the degree of hepatic hematopoietic activity, myocardial structural organization, and the developmental status of lymphoid and endocrine organs demonstrated high discriminatory value in differentiating between the second and third trimesters of gestation. These findings emphasize the importance of internal organ morphology as a key determinant of fetal maturity and viability.

The study highlights the limitations of relying solely on external anthropometric measurements for gestational age estimation and supports the integration of detailed histomorphological analysis into routine forensic examination algorithms. Standardization and systematic application of morphofunctional criteria will enhance the objectivity, reproducibility, and diagnostic accuracy of forensic expert conclusions, contributing to improved medico-legal decision-making in cases of perinatal and intrauterine death.

Overall, the incorporation of expanded morphofunctional evaluation of fetal internal organs represents a scientifically

grounded and practically valuable advancement in forensic diagnostics, with significant medical, legal, and social implications.

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