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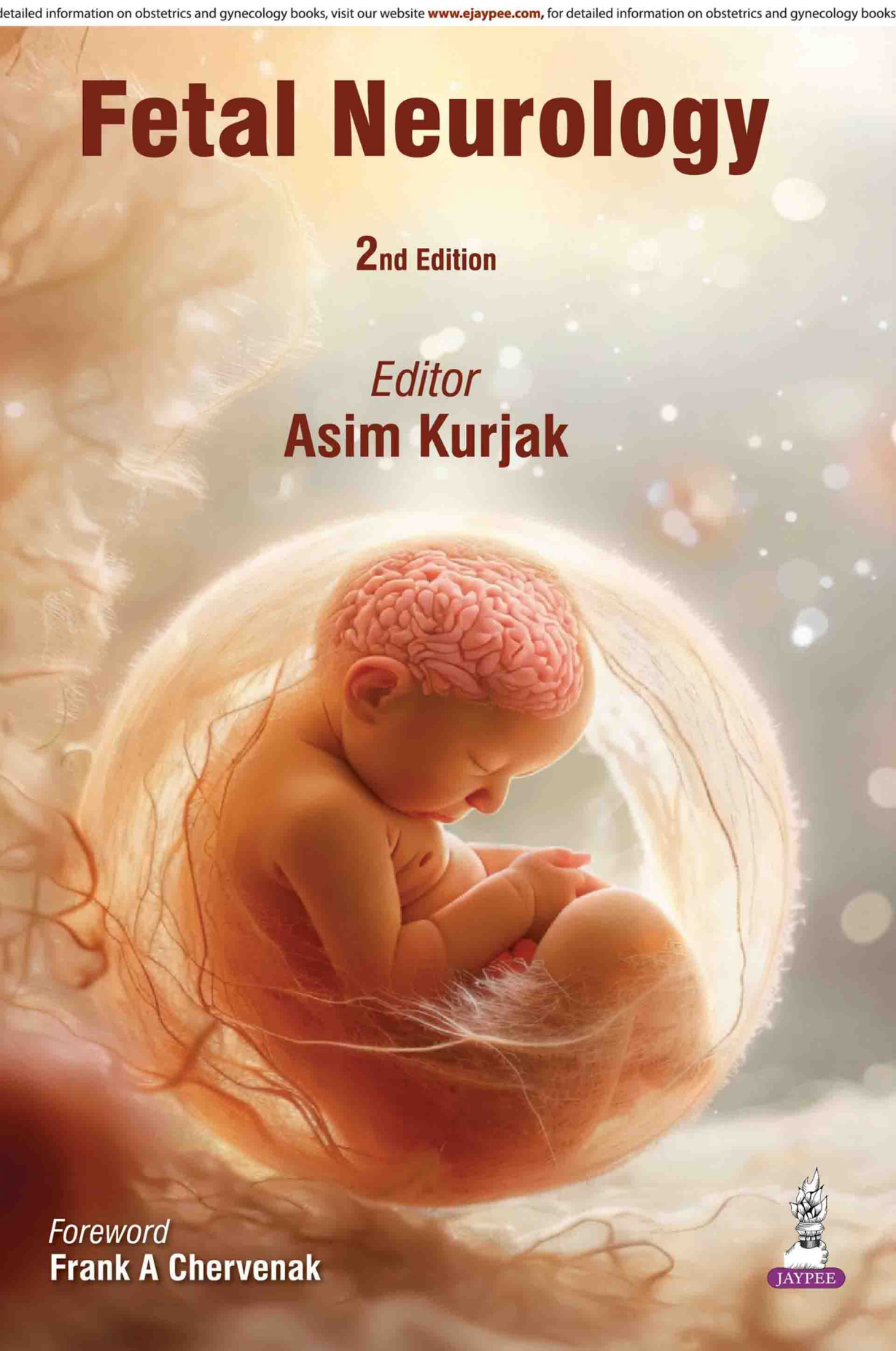
Fetal Neurology

2nd Edition

Editor
Asim Kurjak



Foreword
Frank A Chervenak

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Contents

1. **Embryology of the Human Brain** 1
   Kohei Shiota
2. **Neuroanatomy Visualized by 2D and 3D** 13
   Ritsuko K Pooh
3. **Normal and Abnormal Brain Vascularity** 37
   Ritsuko K Pooh, Asim Kurjak
4. **Neuroscan of Congenital Brain Abnormality** 56
   Ritsuko K Pooh
5. **Neuroscan of Normal and Abnormal Vertebrae and Spinal Cord** 135
   Ritsuko K Pooh, Asim Kurjak
6. **Advances in Fetal Neurophysiology** 153
   Aida Salihagić Kadić, Asim Kurjak
7. **Assessment of Fetal Neurobehavior by 3D/4D Ultrasound** 206
   Asim Kurjak, Ritsuko K Pooh, Milan Stanojević, Badreldeen Ahmed
8. **Fetal Behavior in High-risk Pregnancies Assessed by Ultrasound** 265
   Asim Kurjak, Ritsuko K Pooh, Milan Stanojević, Badreldeen Ahmed
9. **Normal and Abnormal Fetal Hands/Fingers Positioning and Movement in the First and Early Second Trimesters Detected by 3D/4D Ultrasound** 289
   Ritsuko K Pooh, Asim Kurjak
10. **The Evaluation of the Face as a Source of Information of Fetal Neurosystem Integrity** 301
    Asim Kurjak, Guillermo Azumendi
11. **Fetal Neurology in Multiple Pregnancies** 323
    Asim Kurjak, Guillermo Azumendi, Ingrid Marton
12. **From Neonatal to Fetal Neurology: Some Clues for Interpreting Fetal Findings** 341
    (Late) Claudine Amiel-Tison, Julie Gosselin
13. **Continuity between Fetal and Neonatal Neurobehavior** 370
    Milan Stanojević, Asim Kurjak
14. **Maturation of Cerebral Connections and Fetal Behavior** 389
    Ivica Kostović, Miloš Judaš

15. Molecular Genetics and Fetal Brain.....401
Ana Stavljenić-Rukavina, Asim Kurjak, Ritsuko K Pooh

16. Impressive Results of the Clinical Use of Kurjak's Antenatal Neurodevelopmental Test 429
Panos Antsaklis, Asim Kurjak

17. 3D and 4D Sonography in Perinatal Care: From Structural Imaging to Intelligent Functional Diagnostics.....446
Wiku Andonotopo, Asim Kurjak, Muhammad Adrianes Bachnas

18. Prenatal Diagnosis of Neuromuscular Diseases: Clinical Opportunities and Implications 564
Osman Sinanović

19. Kurjak's Antenatal Neurodevelopmental Test: From Fetal Assessment to 10-year Follow-up.....576
Oliver Vasilj, Tatjana Trošt, Dora Marinić

20. Adult Neurology: Everything Starts Antenatally 587
Sanja Tomasović, Koraljka Bačić Baronica, Berislav Ruška

Index 595

CHAPTER 19

Kurjak's Antenatal Neurodevelopmental Test: From Fetal Assessment to 10-year Follow-up

Oliver Vasilj, Tatjana Trošt, Dora Marinić

INTRODUCTION

The psychomotor development of a child is a complex, continuous process that begins intrauterinely and continues throughout life. The development of the fetal central nervous system can be monitored by assessing fetal behavior using the Kurjak's Antenatal Neurodevelopmental (KANET) screening test. In this chapter, we will present the possibility of predicting future sensorimotor development through the use of the KANET test, based on a longitudinal study on the impact of gestational diabetes on the sensorimotor development of 10-year-old children.

GESTATIONAL DIABETES, FETAL BEHAVIOR, AND FUTURE DEVELOPMENT

The foundations for the development of gross and fine motor skills, sensory integration, visuomotor coordination, and cognitive abilities are established already during fetal life,[1-3] from when the entire development is influenced by biological and environmental factors.[4] Among other things, various metabolic factors and an altered intrauterine environment can also affect this process.[5,6] Gestational diabetes may have a specific negative effect on fetal development, the course of pregnancy, childbirth, and the child's future development,[5-9] ranging from metabolic health to psychomotor abilities. Even minimal deviations from reference values can lead to a series of short-term (hypoglycemia, respiratory distress, etc.) and long-term consequences, among which motor and cognitive developmental disorders are significant.[6,9,10]

Fetal behavior, which includes spontaneous or induced fetal movements, reflects the maturity of the central nervous system and the integration of sensory and motor stimuli.[3,11] The most precise assessment is performed with four-dimensional ultrasound, which enables quantitative and qualitative analysis of movements—from head flexion, facial expressions, limb movements, to complex patterns of fetal behavior.[3,11,12] Disorders of fetal behavior have been observed in complicated pregnancies, including those affected by gestational diabetes, with potentially long-term consequences for the child.[13,14] Early screening and detection of disturbed fetal behavior can be performed using the KANET test, which enables early

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identification of neurological risk based on the phenotypic presentation of spontaneous and induced fetal movements.[3,15]

Longitudinal Study on Impact of Gestational Diabetes on Sensorimotor Development of 10-year Olds

Based on the aforementioned facts, the first longitudinal study was conducted demonstrating the predictive value of fetal behavior for later development (at 10 years of age), as well as the possibility of early screening and antenatal detection of developmental risks using the KANET test. At the first measurement point, 82 pregnant women with gestational diabetes and 82 with uncomplicated pregnancies were included. Fetal behavior was assessed and the two groups were compared using the KANET test.[15] Seven aspects of fetal behavior were scored during the four-dimensional ultrasound examination: Head flexion, facial expressions, mouth movements, leg movements, arm movements, hand movements, and the overall impression of movements **(Figs. 1 to 4)**. In four of the seven assessed types of fetal movements, fetuses from pregnancies affected by gestational diabetes achieved significantly lower results (mouth movements, arm movements, hand and finger movements, and general movements), and the level of maternal hyperglycemia was associated with disordered patterns of fetal behavior.

Ten years later, the same participants (now 10 years old) underwent extensive sensorimotor testing. The sample included 50 children from pregnancies with gestational diabetes and 50 from uncomplicated pregnancies. The assessment was performed using standardized tests of fine and gross motor skills, sensory integration, and visuomotor



Fig. 1: Eye blinking.

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Fig. 2: Smiling.



Fig. 3: Facial grimace.

coordination **(Figs. 5 to 8)**. A follow-up was conducted after the antenatal use of the KANET test to assess whether fetal behavior significantly influenced the sensorimotor development of 10 year olds born to mothers with gestational diabetes.

Follow-up—Observed Differences in Sensorimotor Development

Although earlier studies indicate that by later school age the gross motor and sensory integration abilities of children born to mothers with gestational

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Fig. 4: Yawning.



Fig. 5: Fine motor skill testing.



Fig. 6: Gross motor skill testing.

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Fig. 7: Sensory integration testing.



Fig. 8: Visuomotor integration testing.

diabetes become comparable to those of their peers from uncomplicated pregnancies,[16-18] this longitudinal study identified certain differences in both domains. In the follow-up study, children in the experimental group who had shown lower antenatal KANET scores performed worse at 10 years of age on specific tests of muscular endurance and coordination. The differences identified can be explained by several factors. First, by the longitudinal design of the study itself. For the first time the same group of participants assessed as fetuses 10 years earlier was re-examined. The second important factor is that, for the first time, different motor abilities were examined

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using a range of tests, which allowed conclusions to be drawn about specific areas of development—unlike previous studies, which mostly reported only an overall gross motor score.[10] In the domain of sensory integration, a significant difference was found in tactile shape recognition, which assesses stereognosis. Stereognosis is a function of the cortical sensory areas.[19] Studies that used magnetic resonance imaging to compare the brain structures of children born to mothers with pregestational or gestational diabetes and those born to healthy mothers indicate structural cortical changes and their association with certain neurocognitive functions in older primary-school-aged children.[20,21] Additionally, the results of this test may reflect a reduced capacity for bilateral integration, which is consistent with findings from earlier studies.[22]

Regarding fine motor skills, the 10-year follow-up study conducted after the antenatal KANET assessment confirmed earlier findings suggesting that the level of fine motor skills equalizes by later school age.[16-18] Given that children in the experimental group showed significantly altered fetal behavior at the initial measurement point compared to those in the control group, and that numerous studies have confirmed slower fine motor development in children born to mothers with gestational diabetes[6,10] with more pronounced differences at younger ages,[16-18] it can be assumed that the differences in fine motor variables observed at this follow-up were even greater earlier in development.

Previous studies had already indicated that children born to mothers with gestational diabetes may have lower academic achievement, impaired hand–eye coordination, and difficulties with graphomotor skills.[16-18,22,23] These findings were confirmed by follow-up testing carried out after the antenatal KANET assessment. Specifically, children in the experimental group achieved significantly lower results on one of the visuomotor integration variables—the one related to graphomotor skills. Interestingly, the tasks used to assess visuomotor integration were similar to those in an earlier study that identified poorer writing skills in children born to mothers with gestational diabetes.[22] More recent research on the effects of pregestational and gestational diabetes on brain structure and neurocognitive functioning in 10-year-old children suggests that reduced cortical thickness in areas of the occipital lobe may affect visual processing in these children, which is one of the key determinants of visuomotor integration.[21] Taken together, these findings provide the first longitudinal description of the effects of gestational diabetes at 10 years of age, starting from the initial assessment of fetal behavior.

INFLUENCE OF FETAL BEHAVIOR ON FUTURE SENSORIMOTOR DEVELOPMENT

The previously described findings longitudinally confirm the long-term effects of gestational diabetes on child development. Nevertheless,

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the key contribution of this study is the confirmation of the predictive value of antenatal KANET application, providing the first clear evidence that fetal behavior assessment can be used to predict the sensorimotor development of 10 year olds born to mothers with gestational diabetes.

Regression analysis revealed a selective predictive value of the overall fetal behavior model for gross motor skills in children born to mothers with gestational diabetes. Specifically, in this longitudinal sample, predictive value was demonstrated for variables related to agility, explosive strength, and coordination. For the first time, it can be stated that poorer overall fetal behavior in pregnancies affected by gestational diabetes may predict lower motor abilities at the age of 10 years. Agility and explosiveness are abilities that require rapid contraction, which is the capacity of muscles to quickly generate force.[24] Similarly coordination involves the same principle but with an emphasis on timely adaptation to external factors.[25] More precisely, the development of these abilities requires rapid neuromuscular activation and coordination of the afferent–efferent neural pathways.[26,27] According to the results of this study, fetal behavior has predictive value for the future development of gross motor skills in 10 year olds born to mothers with gestational diabetes, particularly in abilities that require speed and coordination of the afferent–efferent neural pathways. Since no predictive value was found in the control group, the results of this study suggest that, in 10 year olds, fetal behavior may have a stronger negative than positive predictive value.

This suggests that normal fetal behavior observed at the first measurement in the control group (during fetal life, under healthy pregnancy conditions) may provide a physiological foundation for later motor development but without significant predictive value—possibly due to various developmental factors occurring over the 10 years of life. On the other hand, disordered fetal behavior observed at the first measurement in the experimental group (during fetal life, under altered intrauterine conditions due to gestational diabetes) may negatively influence gross motor skills at 10 years of age. In other words, while normal fetal behavior does not necessarily determine later motor outcomes lower behavior due to gestational diabetes may be associated with subsequent difficulties in gross motor skills, particularly in agility, explosive strength, and coordination. The overall fetal behavior model showed no predictive value for sensory integration in either children born to mothers with gestational diabetes or their peers born to healthy mothers. This may be related to the fact that sensory integration depends not only on central nervous system development but also on the sensory experiences to which a child is exposed—experiences that are significantly limited during fetal life, as they arise mainly from the repertoire of fetal movements and maternal organ functioning.[28]

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Unlike gross motor skills, no predictive value was found for fine motor skills in children born to mothers with gestational diabetes; however, predictive value was demonstrated for one variable of visuomotor development. This variable was assessed using the Beery–Buktenica test, which evaluates visuomotor abilities through measures of visual perception, motor coordination, and visuomotor integration.[29] In this test, visual perception is assessed through tasks that require recognizing given figures and shapes, motor coordination is evaluated through tasks involving tracing and connecting lines, and visuomotor integration is assessed through tasks in which geometric shapes are copied. Task difficulty is progressively graded from simple to more complex.[29] Altogether, these findings suggest that predictive value is greater when using tests with more complex tasks targeting specific visuomotor integration skills, as is the case with the Beery–Buktenica Visual-Motor Integration (VMI) test.

Interdependence of all Follow-up Findings

The foundations of future development are indisputably laid during fetal life, and the results of this study indicate that fetal behavior can indeed predict future sensorimotor development in children born to mothers with gestational diabetes for certain motor abilities. Nevertheless, the findings support the notion that although fetal motor potential is important, development is also significantly influenced by the extent to which it is stimulated postnatally and throughout childhood,[30] particularly in children whose intrauterine environment was altered. This is further supported by the finding that the predictive value of fetal behavior was evident for most variables in children born to mothers with gestational diabetes, whereas it was much weaker in those born to healthy mothers. More precisely, the results of this longitudinal study suggest that altered fetal behavior associated with gestational diabetes may have negative predictive power—meaning that future deviations in motor development can be anticipated—whereas typical fetal behavior during a healthy pregnancy no longer carries such predictive value in 10-year-old children.

It is also noteworthy that objective measurements of physical activity show that children born from pregnancies with gestational diabetes engage significantly less in high-intensity physical activity. Moreover, the results indicate that fetal behavior has strong predictive value for the future level of high-intensity physical activity in these children. This suggests a risk of reduced participation in high-intensity physical activity among children born to mothers with gestational diabetes, highlighting the importance of systematically encouraging and involving these children in various sports programs that offer opportunities for such activity. Given the growing body of research linking epigenetics with physical activity[31] and with gestational diabetes,[32] this information may be of particular interest for future lines

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of research. If the benefits of high-intensity physical activity for children are well known, and it is also known that children born to mothers with gestational diabetes are at risk of reduced participation in such activities, timely education and lifestyle guidance for parents and families could help prevent this. Children during early life learn by imitating the people around them[33] and habits acquired during early development and childhood affect and are reflected in functioning during adulthood. In this way, by educating and encouraging lifestyle changes in women and families, it is possible to positively influence the functioning, health, and lives of future generations.

CONCLUSION

The results of this longitudinal study clearly confirm for the first time that what happens intrauterinely and the way the fetus behaves can have long-term consequences for the sensorimotor development of a child at the age of 10 years. The KANET test, which enables a detailed insight into fetal behavior through four-dimensional ultrasound, has proven to be a valuable tool for early detection of risks in pregnancies with gestational diabetes. The findings suggest that normal fetal behavior in healthy pregnancies provides a solid foundation for development but does not carry significant predictive value for later ages. On the other hand, disordered fetal behavior in pregnancies affected by gestational diabetes carries long-term consequences and can predict lower development of certain motor abilities. In other words, signs of what may challenge a child's everyday functioning 10 years later can already be detected during fetal life. These findings also carry an important message: Although genetics and intrauterine conditions lay the foundation, what happens after birth—namely how children are stimulated and engaged in movement, play, and physical activity—is equally crucial. Especially knowing that children born to mothers with gestational diabetes participate less frequently in high-intensity activities, it is clear that timely education and guidance of parents and families become key to preventing later difficulties.

In other words, the antenatal KANET test not only opens a window into the child's future but also provides an opportunity to identify risks in time and direct development during early childhood. Thus, this test becomes a powerful public health tool, as it makes it possible from the earliest moments of life to build the foundations of motor skills, health, and quality of life for future generations.

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Fetal Neurology, Second Edition, provides a comprehensive and clinically oriented overview of the developing fetal nervous system. This updated edition reflects major advances in prenatal imaging and neuroscience, emphasizing the integration of structural and functional assessment of the fetal central nervous system.

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Written by internationally recognized experts, this book is an essential reference for obstetricians, perinatologists, neurologists, radiologists, and all professionals involved in prenatal and perinatal care.

Asim Kurjak MD PhD is Professor Emeritus (Obstetrics and Gynecology), Department of Obstetrics and Gynecology, Medical School University of Zagreb, Sveti Duh Hospital, Zagreb, Croatia. He has published more than 1,400 papers which have been cited more than 18,000 times (from: Google Scholar) and has authored, co-authored, or co-edited 129 books. Stanford University has placed academician Kurjak on the list of the 2% most influential scientists in a life-time scientific career. He was named a Highly Ranked Scholar–Lifetime by ScholarGPS for the year 2025. He was recognized and included in the top 0.05% of scientists for his lifetime contribution in the field of ultrasound in medicine.

Dr Kurjak is past President of the International Academy of Perinatal Medicine and the Founder and actual President of the International Academy of Sciences and Arts in Bosnia and Herzegovina. He is the Director of Ian Donald Inter-University School of Medical Ultrasound and an Editor-in-Chief of Donald School Journal of Ultrasound in Obstetrics and Gynecology.

He received a Doctor Honoris Causa from the Universities in Banja Luka, Budapest, Barcelona, Bucharest, Athens, Montevideo, Tomsk, Buenos Aires, St Petersburg, Moscow, Tirana, and Khartoum.

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