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## **Fetal breech presentation: impact on perinatal posture and locomotion**

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# 8

**Epilogue**





Observation of posture and movements in infants has long been used as an item in determining the maturity and the integrity of the central nervous system, especially in preterms [10,26]. Nowadays, with the application of ultrasound, we are able to study posture and movements in an earlier stage, namely in the fetus. Fetal posture and behaviour are the result of an interaction between fetal (neuromotor) development and intra-uterine environmental restraints. By using ultrasound observations, information can be obtained about fetal neuromotor development by observation of the posture and movements of the fetus in its own intrauterine environment, instead of making inferences about fetal behaviour from neonatal observations. More and more, the important role of the influence of prenatal circumstances on postnatal development is being appreciated.

#### ***Effects of ultrasound on fetal and postnatal development***

Extensive use of ultrasound undoubtedly raises the question of its possible effects on fetal and later infant development. The fundamental imaging principles of this technique consist of pulses of ultrasound waves penetrating into patients' tissues, and returning echoes displaying anatomical information. The tremendous growth in usage and the acceptance of diagnostic ultrasound has been fuelled in part by its accumulating history of apparent safety, which now is almost taken for granted. The safety of ultrasound in medicine is largely assumed in the absence of reported adverse effects on human health. A recent review [28] on epidemiological studies regarding prenatal ultrasound showed no association between diagnostic fetal ultrasound exposure and childhood malignancies or on development of dyslexia and neurological development. However, two cohort studies included in this review have been unable to rule out a possible association between ultrasound and left-handedness among males [27,17]. A negative effect on birth weight is reported in one study by Newnham et. al. [19] with a significant increase in the number of babies with a birth weight below the 3rd centile after repeated Doppler ultrasound examinations (which involve continuous ultrasound waves as opposed to pulsed waves in conventional obstetric ultrasound) when compared to a single ultrasound scan during pregnancy. Findings of other researchers however did not support the assumption that birth weight might be reduced by frequent and prolonged

ultrasound imaging [35]. Also, in a follow-up study by Newnham et. al. [20], childhood growth and measures of developmental outcome in the group with repeated ultrasound examinations were similar to those in children who had received a single prenatal scan. So evidence up to now shows no major developmental abnormalities as a result from repeated ultrasound examinations during pregnancy. The most recent statement of the Association for Medical Ultrasound on safety of obstetric ultrasound supports this fact: “Based on the epidemiologic data available and on current knowledge of interactive mechanisms, there is insufficient justification to warrant conclusion of a causal relationship between diagnostic ultrasound and recognized adverse effects in humans.....” [2].

### ***Head posture***

Head-position preference is a manifestation of lateralised behaviour and as such an expression of normal neurological development. Gesell [12] was among the first to describe an asymmetric posture in the healthy month-old infant, called the tonic-neck-reflex, with the head turned to one side, mostly the right. Lateralised behaviour is linked to brain asymmetries. The observation that postural biases can already be observed in infants within one hour after birth [25] supports the idea that intra-uterine factors must play an important role in the development of neonatal lateralised behaviour. Previc’s left-otolithic dominance theory [24] about the origins of cerebral lateralisation in humans is based on asymmetric prenatal development of the fetal inner ear and the labyrinth/vestibular organ. This is thought to result from the asymmetric intrauterine positioning of the human fetus in the last trimester of pregnancy, when about 2/3 of fetuses have their backs to the left side of the mother. This, in combination with the fact that the fetal head is thought to be in a rather fixed position because of its engagement in the bony maternal pelvis in the final weeks of pregnancy, leads to an asymmetric stimulation of the fetal vestibular system during (forward) locomotion of the mother. This asymmetric vestibular stimulation results in dominance for one cerebral hemisphere. For most fetuses this will be the left hemisphere -because of their position in the womb- resulting in a turning of the head to the right because of a dominance in the stimulation of ipsilateral left sternocleidomastoid muscle over the right.

Left-right fetal brain asymmetry, with the left hemisphere significantly larger than the right as measured by in utero ultrasound, has been found at 20–22 weeks gestational age [15]. Reports on fetal and neonatal brain asymmetries date back several decades [8,37]. Recently, Oberto et. al. demonstrated a vascular dominance of the left brain hemisphere in healthy human fetuses between 20 and 40 weeks gestational age [22]. Reports have been made of a right-sided preference for arm activity and thumb sucking already at 10-15 weeks gestational age [13,14], although these findings could not be confirmed by other investigators in a study of lateralized hand-mouth contacts from 12 – 38 weeks [9].

Ververs et. al. [33] did observe a change from a midline to a lateralised—mostly right-sided—head-orientation preference in healthy cephalic fetuses between 36 and 38 weeks gestational age, which is in accordance with Previc’s theory. Breech fetuses could experience a different development of head-position preference from cephalic fetuses. Firstly, because of their different position in the uterus, where a spine located to the left of the mother, would lead to the mirrored behaviour from that of cephalic fetuses. On the other hand, because of the positioning of their head at the upper side of the uterus instead of being engaged in the bony maternal pelvis, breech fetuses could have more freedom of head movement, leading to a less pronounced difference in stimulation between the left and the right otoliths and thus to a weaker manifestation of lateralisation. Thirdly, as a result of the positioning of the fetal head in the uterine fundus, breech babies are known to have a mild skull deformation called dolichocephaly [16,18] consisting of a prominent occiput with a suboccipital shelf, an elongated face and parallel-sided head. In healthy preterms, a change in head shape (side-to-side flattening of the skull) has been shown to influence the development of head lateralisation [11].

By studying head laterality in the healthy breech fetus we had the opportunity to test the left otolithic dominance theory and to determine if anthropometric factors have an influence on the development of head lateralisation before birth. We were able to confirm the findings from earlier reports of a right-sided head-position preference after 36 weeks gestational age in cephalic fetuses. The breech fetuses did not show a significant increase in lateralised head-positions with advancing gestational age.

Our findings in the group of cephalic fetuses on the association between the orientation of the fetal vertebral column and head-position predominance support Previc's left-otolithic dominance theory. These associations are less outspoken in the breech-group (especially for fetuses with a right-sided vertebral column), but this might well be due to the fact that their ability to show lateralised head-position predominance is diminished. This diminished display of head laterality in the breech fetuses may not only be caused by a difference in intra-uterine environment, other factors, such as possible differences in the development of the vestibular system should be considered [31].

Despite a demonstrated difference in fetal head shape between the breech and cephalic fetuses, we found no evidence for its influence on development of prenatal head laterality. Again, the diminished capability of breech fetuses to show head lateralisation should be taken into account in this matter.

An interesting question is what effect these prenatal findings might have on postnatal development of head-position preference. Unfortunately, as we have not yet analysed the data on postnatal head-position preference in our study groups, we cannot answer this question at this moment. But, as no signs of neurological abnormalities were found on standard neurological examination neither in the first week after birth nor at the age of one year, we do not believe that the absence of marked prenatal head lateralisation in the breech group is a sign of major neuromotor abnormality. However, it is quite possible that long-term developmental of skills which are thought to be related to laterality-development as for instance handedness show a different pattern in breech-borns than in cephalic-borns.

### *Arm posture*

Observational studies on healthy preterm infants [26] have led to descriptions for preference postures related to gestational age. Postural behaviour is used as an item to determine the maturation of the neurological system of the neonate [10]. These observations showed that healthy preterm infants had a preferred arm posture consisting in a full arm flexion [32, 36]. In a study by Ververs et. al. on healthy cephalic fetuses [34], arm posture was found to systematically change with advancing gestational age; a significant increase in flexion was

observed for the elbow joint at 16 weeks, for the wrist joint at 28 weeks and for the finger joints at 20 weeks. Because of the early occurrence of especially the flexion in the elbow joint, this finding was interpreted as an expression of neuromaturation, rather than a sole result of intra-uterine movement restriction. Although breech fetuses experience a different intra-uterine environment, movement restriction is thought to be primarily focussed on the lower extremities. As such, we did not expect breech fetuses to show differences in arm posture development when compared to cephalic fetuses.

In our observational study, we found a preference for flexion in elbow, fingers, and wrist in cephalic fetuses. These findings, and the fact that there was no significant change over time during the third trimester of pregnancy complies with the findings from previous research on this subject [34]. We found that, as in the cephalic fetuses, our breech fetuses showed a clear preference for elbow and finger flexion during the third trimester of pregnancy. However, the breech fetuses showed significantly less wrist flexion after 36 weeks gestational age than the cephalic controls.

Around the 36<sup>th</sup> week of pregnancy important changes in fetal behaviour occur, such as the development of head-position preference [33], the emergence of true behavioural states [21] or a shift from unimanual to bimanual hand-face-contacts [9]. The observed difference in wrist flexion around this period could therefore be seen as the result of differences in neuromaturation or neurodevelopment between both groups. With lack of evidence for an abnormal neuromotor development in our breech fetuses, however, we concluded that this difference is most probably due to differences in intrauterine environment.

The fetuses in both groups preferentially held their hands in the vicinity of the fetal head, this means that the breech fetuses had their hands positioned in the upper part of the uterus, whereas the cephalic fetuses' hands were in the lower part of the uterus most of the time. Because of the pear-shape of the uterus and the fact that the lower part of the uterus is surrounded by the bony maternal pelvis, this implies less movement freedom in the lower part of the uterus. Thus our hypothesis is that environmental restrictions led the cephalic fetuses to adopt a wrist posture that is more flexed than that of the breech fetuses. Especially since this difference in flexion was found very late in pregnancy. Postnatal observation of development arm posture after breech presentation



could clarify to what extent the prenatal findings may have an impact in postnatal life.

### ***Prenatal leg posture***

Irrespective of mode of delivery, breech fetuses are at risk of abnormal motor development of the lower extremities. Breech presentation is, for instance, one of the most important risk factors associated with developmental dysplasia of the hip. For fetuses in breech presentation, the risk of developmental dysplasia of the hip is estimated to be at least 2.7 % for girls and 0.8 % for boys [7]. Although ample information on prenatal leg posture in breech fetuses can be found in the literature, this is mostly based on short and often single (ultrasound) observations.

As far as we know, we were the first to perform a structured, longitudinal, observation of the development of prenatal leg posture in both breech and cephalic fetuses in the third trimester of pregnancy.

In the group of breech fetuses we found a clear preference for a leg posture with extended knees when compared to the cephalic fetuses. The cephalic fetuses on the other hand showed significantly more crossing of the lower part of the legs than the breech fetuses. For both findings, no significant change over time could be observed in either group.

The fact that the breech fetuses preferred a posture with knee extension was not surprising, since the most commonly occurring type of breech presentation is the so-called frank breech. It is remarkable, however, that the differences between the two groups could already be observed starting from early in the third trimester, when intra-uterine movement restriction is not thought to be significant and mostly the breech will not be engaged yet in the maternal pelvis at this time. The findings stayed fairly stable over the studied period starting from 33 weeks until birth, implying that the influence on leg posture did not change with prolonged duration of the breech presentation.

A leg position with crossing of one lower leg over the other, as we observed in our cephalic fetuses, could lead to a more abducted hip position in utero than when the legs are uncrossed. As abduction of the hip joint facilitates normal development of the femoral head and the acetabulum [6], the observed preference leg position of our breech fetuses with extended legs and uncrossed

lower legs could be one of the reasons why breech fetuses show a significant risk of developing neonatal hip joint instability.

Our data show the extensive influence of intra-uterine environment on fetal leg posture. The fact that none of the children in our study-group showed signs of congenital hip dysplasia probably demonstrates the great ability of infants to “recover” from prenatal influences as we have also demonstrated in the data on later postnatal development in chapters 5 and 6. To be able to identify which children are really at risk for abnormal hip joint development, much larger study groups are needed. Also, the 2D ultrasound technique which we applied is not very suitable for studying the fetal hip joint, especially in breech fetuses. 3D or even 4D ultrasound could show big advantages in this respect.

### ***Postnatal leg posture***

The first report on longitudinal postnatal observations of the effect of breech presentation on lower limb movements was performed by Sival et. al. [30]. They observed differences in leg reflexes between breech- and cephalic-born infants, together with limited extension of the hip-joint during the first 12 weeks after birth. In the same study qualitatively normal fetal general movements were observed in the breech fetuses, suggesting absence of neurological abnormality [23]. The differences between the breech- and cephalic-born children were thought to arise from alterations in proprioceptive feedback mechanisms as a result of intra-uterine movement restriction of the legs.

In one study by Bartlett et. al. comparing breech and cephalic-born infants [4], minor group differences were detected in leg functions at 6 weeks. These transient differences were thought to result from mechanical effects of the breech presentation and not from differences in neurological development, as no persistent, inherently different pattern of motor development could be observed. The same group did an examination of thirteen primitive reflexes at birth, 6 weeks and 3 and 5 months [3]. No significant differences in the reflexes (including upper and lower extremity grasp, lower extremity placing and stepping reflexes) were observed between the breech and cephalic groups. To our knowledge, all previous studies on this subject lack extensive longitudinal and repeated fetal postural assessment to relate to the postnatal data.

Going from the prenatal to the postnatal environment means changing from a situation with a rather large amount of environmental restrictions to an environment with significantly less restrictions from the environment. On the other hand, the prenatal situation is one where gravitational forces have less impact on posture and movements (because of the presence of amniotic fluid), in contrast to the situation after birth.

In our study on postnatal leg posture during general movements the breech infants showed significantly more hip flexion in the first 4 to 6 weeks after birth than the cephalic infants. Between 2 and 4 weeks postnatal age a significant decrease in hip flexion together with an increase in hip extension for the breech fetuses could be observed. These significant changes in the first postnatal weeks give an illustration of the prenatal movement restriction experienced by these infants. The cephalic infants did not show significant changes in time for hip posture during the first six weeks, implicating that the change from pre- to postnatal life did not lead to a substantial change in movement freedom in the hips for this group.

No significant differences in knee posture between both groups were observed. Thus the striking prenatal difference between both groups with significantly more knee extension for the breech fetuses that we reported on in chapter 4 has already disappeared within two weeks after birth.

Our findings show that the greatest impact of prenatal leg movement restriction in breech infants can be observed in the first 6 weeks after birth and that hip posture seems to be more influenced by prenatal restrictions than knee posture. The observed differences between the breech and the cephalic babies were transient, as from 12 weeks on no significant differences were seen anymore between both groups, which is in accordance with earlier reports.

The change from supine to a vertical position had more impact on hip posture in the breech (significantly more hip extension) than in the cephalic group (no significant change in hip posture). Differences in hip posture between the groups were also less outspoken in vertical position than in supine. Together, this implies that the impact of gravity exceeds that of the prenatal hip movement restriction in the breech infants.

When comparing the data from the last prenatal observation with those from the first postnatal observation, we found continuity for hip posture in both groups

and for knee extension only in the breech group. So the prenatal influence seems to have lasting impact on postnatal hip posture in both groups, while for prenatal knee posture continuity with the postnatal findings could only be found in the breech infants. Prenatal movement restriction for the knees in breech presentation probably has less impact on postnatal behaviour than that for the hip joint.

Prolonged movement restriction in the human fetus as a result of oligohydramnios can affect the normal development of bones and joints. Confirmation of the fact that prenatal movement restriction is present in breech presentation can be found in the significant changes in hip joint posture in the first weeks after birth. In contrast to the situation with prolonged oligohydramnios, however, the changes observed in prolonged breech presentation are transient. At least this is the case in infants who are not affected by congenital hip dysplasia.

### ***Unsupported walking***

In 1993 Sival and colleagues reported their longitudinal study on possible effects of breech presentation on development of leg motor functions [30]. Associations were found between the amount of time spend with the hips in flexion during the first 12 postnatal weeks in the breech-born children and an abnormally 'flexed' walking pattern at 12-18 months; seven out of twelve breech-born infants showed an abnormal walking pattern with a small flexion in the hips resulting in a slight forward bending of the trunk. A positive magnet response at 6 months was also found to be associated with the abnormal walking pattern. These findings were thought to possibly be mediated by alterations in proprioceptive feedback mechanisms. No differences were found between the breech and cephalic groups in ages at which developmental milestones were achieved. Based on these findings Sival et. al. suggest a long-term effect of prenatal breech position on functional hip dynamics during locomotion. Their conclusions were based on inspection of video recordings.

In our study on unsupported walking at the age of 2.5 years we recorded exact 3-D coordinates of the different joint-angles during locomotion with the Optotrak-system (Northern Digital Inc. Canada). We aimed to investigate further the possible role of prenatal breech position, and thus prenatal

environmental constraints, on qualitative aspects of locomotion. The studied children had more than 6 months experience in independent walking, because in the literature there is a general consensus that the development of independent walking consists of two phases. The first phase of approximately 6 months primarily involves stabilisation of the trunk, while the second phase is regarded as fine-tuning of the movement that lasts till the age of 7–8 years.

In the first part of our study, a gait analysis based on footprint patterns and gait kinematics around the hip joint, measured by goniometers, was carried out. Gait analysis based on footprint patterns is a common method to determine walking parameters in toddlers [1,5]. No significant differences in step length, step width, foot rotation, foot rotation asymmetry, hip flexion, hip extension and range of motion of the hip were detected during gait between the two groups of children. In accordance with the study by Sival et. al.. there was no difference in the age when the children started walking, i.e. they reached this developmental milestone around the same age. The fact that none of the measured gait parameters differed between the two groups suggests that prenatal breech position does not affect functional hip dynamics during walking at 2.5 years of age.

In the second part of this study, the children were challenged to cross a gap that was widening with every successive trial until their maximum attainable crossing distance was reached. This second part of the study was especially carried out because a possible effect of prenatal breech position on postnatal hip dynamics should be more prominent in gap crossing than in normal gait as this functional task requires a larger range of motion of the hip joint, rather than in a conventional gait study.

As was expected, gap crossing significantly differed from, and was more challenging, than normal gait. However, no significant differences in achieved maximum gap width were found between the study group and the control group which means that the children who were in prenatal breech position performed just as well in this task as the control children. However, nearly 50% of the breech-born children used significantly less (on average 22°) extra hip flexion to achieve the same gap width in comparison with the control group. Given the finding that there was no significant difference between these two groups in the total amount of extra hip motion involved in maximum gap crossing, it seems

that this subgroup of children must apply extra hip **extension** in the trail leg, (although not significantly more than the control group), to compensate for the smaller amount of extra flexion in the leading leg. Based on previous research, which showed decreased extension and increased flexion capabilities in the first 12 weeks after birth for children after prenatal breech position, one would predict precisely the opposite of the current findings.

Given the relative small sample size of the present study, apparently the findings should be treated with care. However, when realising that the extra amount of flexion and extension are not absolute measures, but relative to the flexion and extension in walking, we had two different explanations for our findings. Firstly, it could be that part of the children in the breech-group did indeed use less hip flexion and more hip extension (in absolute terms) during gap crossing. Or, secondly, these children use the same amount of hip flexion and extension (in absolute terms) as the control children during gap crossing, but they have a more flexed walking pattern, thus starting off with more hip flexion anyway. This was not found in the data on gait analysis. However, in our study joint flexion was defined relative to a so-called reference measurement which was the normal, freely selected upright posture of the child. So it could very well be that part of the study group already adopted a more flexed posture in the reference measurement. In walking, a preferentially flexed posture does not directly need to pose a problem, but in order to cross a large gap, the possible amount of extra flexion in the leading leg is therefore limited. In light of the previously mentioned study by Sival et. al., which showed that about 60% of the children in the breech group had a flexed walking posture at 12–18 months, the second explanation could fit the current findings. But again, the children with less extra flexion did not differ significantly from the control group on the maximum distance crossed, or in the amount of extra degrees involved in achieving this maximum gap width. In this regard, the functioning of the hips, measured in the range of motion, is not affected by their prenatal breech position. Merely, their solution for performing the challenging task of gap crossing is different, with the application of less extra flexion, but more extra extension.

The question whether the observed differences between the two groups can solely be explained by prenatal environmental restraints or (at least in part) by

intrinsic neurological causes in breech fetuses, as suggested by some authors, cannot be answered through these data. At neurological examination after birth and at one year of age, though, no neurological abnormalities were observed in the participating children.

However, prenatal breech position seems not to have a long-term effect on locomotion at a functional level, because children who were in breech position before birth perform just as well as the control group on both our tasks (walking and gap crossing). Our negative findings at the studied age are in concordance with the transient, effects on motor performances found by previously mentioned authors.

These findings illustrate once more the transient, age-dependent nature of the effects of prenatal breech presentation when considering hip function in a functional task. Nonetheless, subtle differences remain between the groups in the execution of the instructed task. Indisputably, the breech-born children show a remarkable ability in finding solutions to “recover” from prenatally experienced movement restrictions in both their hips and knees.

### ***Environmental influence on neuromotor development***

Intra-uterine environment seems to be an important determinant of both intra- and extra-uterine development. This is demonstrated by the observed differences between healthy breech and cephalic fetuses and infants. Some of our hypotheses at the start of the project were supported by our findings, others were rejected.

For the development of head lateralisation our hypothesis was that this process could be different in breech infants, because of the different environment experienced by these fetuses when compared to cephalic fetuses. Our group of breech fetuses indeed showed a diminished capability to develop a prenatal lateralised head-position preference. On the other hand, contrary to the findings in healthy preterms, a change in fetal head shape as is the case in breech fetuses did not seem to have an influence on the development of head-position preference.

For arm posture a difference between breech and cephalic fetuses was not expected. This proved to be true for elbow- and finger posture, nevertheless development of wrist posture in the final weeks of pregnancy seemed to be

influenced by the difference in intra-uterine environment. In this aspect breech fetuses showed significantly less wrist flexion, probably because of less movement restriction in the uterine fundus where the fetal hands are preferentially positioned.

As we expected, the influence of breech presentation on prenatal leg posture was the most prominent. Prenatally the breech fetuses showed significantly more knee extension and less crossing of the lower legs, probably leading to less abduction in the fetal hip joint. The finding that the differences were already observed early in the third trimester and that prolonged duration of prenatal exposure to the different environment did not lead to a change in the observed effects, led us to think that intra-uterine environment may not be the only factor contributing to this effect. On the other hand, no major neurological abnormalities were found in our study groups at neurological examination. Suggesting that if a neurodevelopmental difference exists between both groups, it will probably be no more than a subtle difference not leading to detectable neurological abnormalities postnatally. The transition from pre-to postnatal environment for leg posture showed confirmation of the prenatal restrictive influence on hip posture in the changes in hip posture during general movements in the first 4 to 6 weeks after birth. Surprisingly, the prenatal differences in knee posture between the breech and cephalic fetuses had already disappeared at examination at 2 weeks postnatal age. The transient nature of the findings confirms even more the fact that the observed differences were the result of adaptations to the prenatal environment as opposed to permanent abnormal (neuromotor) developmental. The speed at which normalisation of leg posture occurs, within 6 weeks after birth, is remarkable. And this is only emphasized by the fact that at the age of 2.5 years no functional differences in between both groups can be found anymore during walking and gap crossing.

### ***Future perspectives***

With the increasing demand for optimal counselling of parents on health and development of their (unborn) child, knowledge of neuromotor development fetuses and infants is gaining importance. The fetus is able to adapt to changes in intra-uterine environment in ways that are dependent on the gestational age.



The healthy neonate adjusts in its own ways to different changes in the environment.

Further postnatal research on the development of head posture, arm posture and movements, behavioural asymmetries and general movements is necessary. This will consequently lead to an abundance of new information on the neuromotor development of breech fetuses and infants. Bit by bit, this information may lead to enhanced understanding of the aetiology of breech presentation as well as the aetiology of the sequelae of breech presentation as for instance congenital hip dysplasia. Multi-disciplinary investigation (with a collaboration between obstetricians, paediatricians, developmental neurologists, movement scientists, physical therapists, etc) as in our research project will be of utmost importance, since information on only one aspect of development will leave out a lot of other important contributing factors. Because of the dynamic nature of neuromotor development in fetuses and infants, sole prenatal or sole postnatal observations will fail to paint the full picture on the influence of changes in perinatal environment.

## References

1. Adolph KE, Vereijken B, Byrne K, Ilustre I. Footprint method of gait analysis: New insights into infant walking. 1996.
2. AIUM. Conclusions Regarding Epidemiology for Obstetric Ultrasound. 2005.
3. Bartlett, D., Piper, M., Okun, N., Byrne, P., and Watt, J. Primitive reflexes and the determination of fetal presentation at birth. *Early Hum Dev* 1997;48: 261-273.
4. Bartlett, D. J., Okun, N. B., Byrne, P. J., Watt, J. M., and Piper, M. C. Early motor development of breech- and cephalic-presenting infants. *Obstet Gynecol* 2000;95: 425-432.
5. Boenig, D. D. Evaluation of a clinical method of gait analysis. *Phys Ther* 1977;57: 795-798.
6. Bradley, J., Wetherill, M., and Benson, M. K. Splintage for congenital dislocation of the hip. Is it safe and reliable? *J Bone Joint Surg Br* 1987;69: 257-263.
7. Chan, A., McCaul, K. A., Cundy, P. J., Haan, E. A., and Byron-Scott, R. Perinatal risk factors for developmental dysplasia of the hip. *Arch Dis Child Fetal Neonatal Ed* 1997;76: F94-100.
8. Chi, J. G., Dooling, E. C., and Gilles, F. H. Left-right asymmetries of the temporal speech areas of the human fetus. *Arch Neurol* 1977;34: 346-348.

9. de Vries, J. I., Wimmers, R. H., Ververs, I. A., Hopkins, B., Savelsbergh, G. J., and van Geijn, H. P. Fetal handedness and head-position preference: a developmental study. *Dev Psychobiol* 2001;39: 171-178.
10. Dubowitz, V. Neurological assessment of gestational age in newborn. *Arch Dis Child* 1969;44: 135-
11. Geerdink, J. J., Hopkins, B., and Hoeksma, J. B. The development of head position preference in preterm infants beyond term age. *Dev Psychobiol* 1994;27: 153-168.
12. Gesell A. The tonic neck reflex in the human infant. *The Journal of Pediatrics* 1938; 13: 455-464.
13. Hepper, P. G., Shahidullah, S., and White, R. Handedness in the human fetus. *Neuropsychologia* 1991;29: 1107-1111.
14. Hepper, P. G., McCartney, G. R., and Shannon, E. A. Lateralised behaviour in first trimester human foetuses. *Neuropsychologia* 1998;36: 531-534.
15. Hering-Hanit, R., Achiron, R., Lipitz, S., and Achiron, A. Asymmetry of fetal cerebral hemispheres: in utero ultrasound study. *Arch Dis Child Fetal Neonatal Ed* 2001;85: F194-F196.
16. Kasby, C. B. and Poll, V. The breech head and its ultrasound significance. *Br J Obstet Gynaecol* 1982;89: 106-110.

17. Kieler, H., Axelsson, O., Haglund, B., Nilsson, S., and Salvesen, K. A. Routine ultrasound screening in pregnancy and the children's subsequent handedness. *Early Hum Dev* 1998;50: 233-245.
18. Lubusky, M., Prochazka, M., Langova, M., Vomackova, K., and Cizek, L. Discrepancy in ultrasound biometric parameters of the head (HC - head circumference). *Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub* 2007;151: 323-326.
19. Newnham, J. P., Evans, S. F., Michael, C. A., Stanley, F. J., and Landau, L. I. Effects of frequent ultrasound during pregnancy: a randomised controlled trial. *Lancet* 1993;342: 887-891.
20. Newnham, J. P., Doherty, D. A., Kendall, G. E., Zubrick, S. R., Landau, L. L., and Stanley, F. J. Effects of repeated prenatal ultrasound examinations on childhood outcome up to 8 years of age: follow-up of a randomised controlled trial. *Lancet* 2004;364: 2038-2044.
21. Nijhuis, J. G., Prechtl, H. F., Martin, C. B., Jr., and Bots, R. S. Are there behavioural states in the human fetus? *Early Hum Dev* 1982;6: 177-195.
22. Oberto, M., Gaglioti, P., Mensa, M, Ogge, G., Ciriminna, V., Scata, M., Panattoni, G., and Todros, T. Assessment of brain vascularization and blood flow in human fetus using quantitative three-dimensional power Doppler sonography. *Ultrasound in Obstetrics & Gynecology* 2007;30: 417-417.
23. Prechtl, H. F. and Einspieler, C. Is neurological assessment of the fetus possible? *Eur J Obstet Gynecol Reprod Biol* 1997;75: 81-84.

24. Previc, F. H. A general theory concerning the prenatal origins of cerebral lateralization in humans. *Psychol Rev* 1991;98: 299-334.
25. Ronnqvist, L. and Hopkins, B. Head position preference in the human newborn: a new look. *Child Dev* 1998;69: 13-23.
26. Saint-Anne Dargassies S. Neurological development in the full-term and premature neonate. Amsterdam: Elsevier; 1977.
27. Salvesen, K. A., Vatten, L. J., Eik-Nes, S. H., Hugdahl, K., and Bakketeig, L. S. Routine ultrasonography in utero and subsequent handedness and neurological development. *BMJ* 1993;307: 159-164.
28. Salvesen, K. A. Epidemiological prenatal ultrasound studies. *Prog Biophys Mol Biol* 2007;93: 295-300.
29. Sival, D. A., Visser, G. H., and Prechtl, H. F. Does reduction of amniotic fluid affect fetal movements? *Early Hum Dev* 1990;23: 233-246.
30. Sival, D. A., Prechtl, H. F., Sonder, G. H., and Touwen, B. C. The effect of intra-uterine breech position on postnatal motor functions of the lower limbs. *Early Hum Dev* 1993;32: 161-176.
31. Tymnik, G., Donat, H., and Fischer, B. [Abnormal obstetric presentation--consequence of defective vestibular function (author's transl)]. *Zentralbl Gynakol* 1981;103: 952-956.
32. van Oostenbrugge, R. J. and Vles, J. S. Posture in low-risk pre-term infants of 30 weeks postmenstrual age. *Brain Dev* 1995;17: 253-255.

33. Ververs, I. A., de Vries, J. I., van Geijn, H. P., and Hopkins, B. Prenatal head position from 12-38 weeks. I. Developmental aspects. *Early Hum Dev* 1994;39: 83-91.
34. Ververs, I. A., Gelder-Hasker, M. R., de Vries, J. I., Hopkins, B., and van Geijn, H. P. Prenatal development of arm posture. *Early Hum Dev* 1998;51: 61-70.
35. Visser, G. H., de Vries, J. I., Mulder, E. J., Ververs, I. A., and van Geijn, H. P. Effects of frequent ultrasound during pregnancy. *Lancet* 1993;342: 1359-1360.
36. Vles, J. S., Kingma, H., Caberg, H., Daniels, H., and Casaer, P. Posture of low-risk preterm infants between 32 and 36 weeks postmenstrual age. *Dev Med Child Neurol* 1989;31: 191-195.
37. Witelson, S. F. and Pallie, W. Left hemisphere specialization for language in the newborn. Neuroanatomical evidence of asymmetry. *Brain* 1973;96: 641-646.

