**ESM12. Specific Considerations**

*Pediatric Brain Ultrasound*

The early work by Helmke and Hansen [1] investigating transorbital ultrasound imaging of the optic nerve sheath (ONS) still remains fundamental to our understanding of the ONS response to changes in ICP, especially in children. The described technique involves gently placing a high frequency, small footprint, linear array probe over the gel covered upper eyelid, angled slightly infero-medially in order to visualize the posterior aspect of the globe, the optic nerve and optic nerve sheath. Measurements are performed 3mm posterior to the sclera [2–5]. However, a lack of consensus regarding the optimal age-related ONSD cut-off value in children has been a short coming of the technique [6]. Recommendations for the ONSD measurement cutoff values in children include:

* more than 5mm in children older than 4 years and more than 4mm in children under the age 4 years be considered definitely enlarged has been widely used [1].
* ONSD value greater than 4 mm in children under 1 yo, and greater than 4.5 mm in older children should be considered abnormal [7].
* an age related cut-off point for normal ONSD values of 4.0 mm in children under the age of 1 year, and 4.5 mm in children over the age of 1 year [8]. mean ONSD value of 5.6 ± 0.6 mm in symptomatic children compared to 3.3 ± 0.6 mm in a control group [9].
* a cut-off point of 4.2 mm with a sensitivity of 100% and specificity of 86%, as the upper limit of normal, with measurements ≥ 4.5 mm indicative of raised ICP [10]

McAuley et al suggested that repeat ONSD measurements were more useful in detecting raised ICP, especially in children with hydrocephalus [11]. This approach appears to be very sensible given the inter-individual variation in baseline ONSD measurements and our limited understanding of the elastic properties of the ONS. Steinborn et al recently reported higher ONSD cut-off values than previously reported, suggesting that better high resolution ultrasound imaging provided a better understanding of the ultrastructure of the optic nerve sheath complex [12]. A distinct limitation with most of these studies has been the lack of comparison between ONSD and the gold standard of invasive ICP measurement.

In the largest study to date in children, examining the relationship between ONSD measurement and invasive ICP readings, Padayachy et al [6] described the following ONSD values with the best diagnostic accuracy in children with a closed anterior fontanelle:

ICP > 5mmHg – 5mm,

ICP > 10mmHg – 5.2mm,

ICP >15mmHg – 5.5mm and

ICP > 20mmHg – 5.8mm

The current limitations of ONSD measurement in children, relate to a lack of consistency in the literature [6–8, 12, 13]. Most studies only compare ONSD measurement to other noninvasive, surrogate markers of ICP. In children, the age-related variation makes interpretation of the ONSD cut-off values somewhat challenging.

ONSD measurement has also demonstrated a poor relationship with shunt failure in pediatric hydrocephalus. Invasive ICP measurement using lumbar puncture CSF pressure also differs from direct intracranial ICP measurement, making comparison between non-invasive and invasive techniques difficult [14].

In an effort to address some of these limitations in diagnostic accuracy, recent studies have combined ONSD measurement with dynamic parameters like venous TCD [15] and deformability of the ONS [6, 16].Improving diagnostic accuracy is essential for the widespread use of any non-invasive technique, and novel approaches to these issues are required.

Transcranial imaging

Transcranial sonography provides an ideal imaging modality in the neonatal ICU. Linear array, high frequency probes are useful for scanning through the patent fontanelle, but require a detailed, multiplanar understanding of the intracranial anatomy, particularly in the sagittal and coronal planes. Alternate windows include the temporal, mastoid and lambdoid views. Exquisite detail and rapid diagnosis in conditions like hydrocephalus (Images 2-7), intracranial tumors (Images 8-10b), hemorrhage, congenital anomalies, infections, hypoxic-ischemic damage and vascular malformations underscore the value of transcranial ultrasound and Doppler as a bedside diagnostic tool [17, 18]. Published guidelines and the ALARA (As Low As Reasonably Achievable) principle define thermal and mechanical indices generally accepted as safe.

*Pregnancy related neurological disturbances*

Transorbital imaging

An increase in ICP is an ominuous feature associated with neurological sequelae in patients with severe preeclampsia during pregnancy. Early and reliable noninvasive detection of raised ICP in preeclampsia may be vital in limiting or even preventing the associated neurologic sequelae. Preeclampsia is a maternal disease occurring in about 8% of pregnancies, so the benefit of a practical technique like ultrasound-based assessment of the ONSD as a noninvasive marker of ICP leaves little doubt [19]. Dubost and colleagues reported that in about 20% of preeclamptic patients, the ONSD measurement exceeded 5.8mm. This measurement was found to be consistent with an ICP > 20mmHg. Importantly, this study also found that the ONSD measurements returned to a value that was close their baseline values at day 7 postpartum, suggesting that the change in ONSD measurement could also be used to monitor treatment outcome [19]. The authors concluded that this easy-to-perform technique was potentially useful in detecting and monitoring the treatment of raised ICP in preeclamptic patients. A recent study by Simenc et al [20] also supported the earlier work by Dubost et al [19]. The authors also described an increase in the optic disc height of more than 1 mm which was observed in 78% of patients with severe preeclampsia as a feature associated with papilledema on transorbital sonography. These features were present before delivery and on day 1 post-delivery, but not on day 4 post-delivery in the patients with severe preeclampsia [20]. In a study investigating point of care ultrasound (POCUS) derived-markers of pulmonary and cardiac dysfunction in late onset severe preeclampsia, these were compared with an ONSD > 5.8mm as a marker of raised ICP. The authors detected an increased ONSD in 28% of preeclamptic women with features of severe disease. POCUS and ONSD measurement were found to be useful adjuncts to clinical examination in the care of complex preeclamptic obstetric patients [21].

A unique study performed in pregnant women, examined the feasibility of fetal ONSD measurement on sonography as a marker of ICP. Three fetuses with intracranial lesions were compared to 42 normal fetuses. The authors describe the ONSD measurement in the fetuses with intracranial lesions as being at least 2SD higher than age matched controls. They also noted an increase from 1.2mm at 23 weeks to 2.6mm at 36 weeks in the normal fetuses, confirming the feasibility of sonographic measurement of the ONSD as an early tool for diagnosing raised ICP [22].

Ultrasound-based assessment of the ONSD as a tool for detecting raised ICP in preeclamptic patients appears to a useful technique.

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