Brain Ultrasound in neonates and infants: still an important first line imaging

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Established applications, value of Doppler-US + new aspects

• Basic neurosonography
  - well established

• New applications & modern techniques
  - broadened US potential
    • Doppler & (amplitude coded) color Doppler US
    • high resolution US (HR)
    • harmonic imaging (HI)
Established applications, value of Doppler-US + new aspects

New aspects & new US methods

- increasingly integrated into standard imaging
  - transcranial approach (TCI)
  - spinal canal
    + extended view
  - US of the infants orbit & skull
  - contrast-enhanced US
  - 3DUS
Introduction

Pediatric neurosonography predominately relies on

• **transfontanellar US**
  - for viewing the neonatal brain, including DS
  = modality of choice for bedside assessment

• **small part US of the spinal canal**
  - for evaluating the neonatal spinal canal

Many clinically important indications established
Basic US requisites

• **Sector array**: transfontanellar & transtemporal

• **Linear array**: brain surface, skull, orbit, spine …

• **Frequency**: 15 / 10 - 2 MHz
  - for (N)ICU: (a)CDS / PW-DDS capabilities
    + transfontanellar & axial / transtemporal views

• **Knowledge & experience & prudent skill**
  - **mind:** low output (Watt) = low MI/TI
  - aim at short investigation time in preterm babies!
Normal brain US images

Standardized & comprehensive assessment

- (para-) sagittal
- coronal
Normal brain US images

Standardized & comprehensive documentation

Minimaldokumentation: Anforderung für den Normalbefund

- Interhemisphärenspalt
- Corpus callosum
- Seitenventrikel
- Cavum septi pellucidi
- Stammganglien
- Fissura Sylvii

Koronarschnitt durch die Vorderhörner der Seitenventrikel

- Interhemisphärenspalt
- Corpus callosum
- Seitenventrikel und III. Ventrikel
- Cavum septi pellucidi
- Stammganglien
- Fissura Sylvii

Koronarschnitt durch die Seiten- und den III. Ventrikel (Höhe der Foramina Monroi)

- Interhemisphärenspalt
- Corpus callosum
- Seitenventrikel und III. Ventrikel
- Cavum septi pellucidi
- Stammganglien
- Fissura Sylvii

Koronarschnitt durch die Hinterhörner und Trigona der Seitenventrikel

- Interhemisphärenspalt
- Corpus callosum
- Hinterhörner und Trigona der Seitenventrikel mit
- Plexus choroideus
- Periventrikuläres Marklager

Medianer Sagittalschnitt durch den Vermis cerebelli

- Corpus callosum
- Cavum septi pellucidi
- Plexus choroideus des III. Ventrikel
- III. und IV. Ventrikel
- Vermis cerebelli

Parasagittalschnitt links und rechts durch die Seitenventrikel

- Seitenventrikel
- Stammganglien (Nucleus caudatus und Thalamus)
- Plexus choroideus

Parasagittalschnitt periventrikular insbesondere bei Frühgeborenen

- Periventrikuläres Marklager
Additinal sections

- **Brain surface** => HR-US, linear transducer
  - compulsory in special conditions
Additinal sections

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  - compulsory in special conditions
    - infarction
    - „battered child“
    - thrombosis
    - gyration disorders
Additinal sections

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  - compulsory in special conditions
    • infarction
    • „battered child“
    • thrombosis
    • gyration disorders

• **Axial acquisition** => sector Tdx
  - helpful, lower frequency
  e.g., extra-axial collections
    brain stem & posterior fossa, …
How to measure

- **Standardized sections**
  - all pathology
  - in 2 planes

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How to measure

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  - all pathology
    • in 2 planes
How to measure

• **Standardized sections**
  - all pathology
    • in 2 planes
  - essential
    follow-up
How to measure

- **Standardized sections**
  - all pathology
    - in 2 planes
  
  - essential
    for follow up
  
  medico-legal aspects, ...

- use „landmarks“
  as a reference
  
  e.g. midline structures, ...
Typical US findings

• PVE / PVL
  in preterm babies
  - apnoea, hypoxia, low RR, ...
Typical US findings

• **PVE / PVL**
  - in preterm babies
  - apnoea, hypoxia, low RR, ...

• **US findings:**
  - periventricular echogenicity ↑
  - particularly suspicious if
    - patchy,
    - inhomogeneous,
    - asymmetrical ...
Typical US findings

• PVE / PVL
  in preterm babies
  - apnoea, hypoxia, low RR, ...

• US findings:
  - periventricular echogenicity ↑
  - patchy, inhomogeneous, ...

• Initially often difficult to differentiate
  - may be normal in immaturity

  clue to diagnosis => follow-up (cysts, ...)
Most frequent query: IVH

• Typical in preterm babies
  - vary with gestational age
Most frequent query: IVH

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- **SEB = IVH I°**
  DD: plexus bleed congested plexus
Most frequent query: IVH

- Typical in preterm babies
  - vary with gestational age
- SEB = IVH I°
  - DD: plexus bleed
  - congested plexus

- IVH II° + III°

- III + secondary PVH
  - = IVH IV° in old terminology
Most frequent query: IVH

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  - vary with gestational age

- SEB = IVH I°
  DD: plexus bleed
  congested plexus

- IVH II° + III°

- IVH III + secondary PVH
  \Rightarrow hydrocephalus & cysts
Most frequent query: IVH

- Typical in preterm babies
  - vary with gestational age
- \textbf{SEB = IVH I°}
  - DD: plexus bleed
    - congested plexus
- \textbf{IVH II° + III°}
- \textbf{IVH III° + secondary PVH}

DD: hemorrhagic infraction for other reasons
Other cranial hemorrhages

• In a term neonate
  - brain stem bleed
Other cranial hemorrhages

- In a term neonate
  - brain stem bleed
- After trauma
  e.g., cesarean section
  - tentorial hemorrhage
Other cranial hemorrhages

- In a term neonate
  - brain stem bleed
- After trauma
  - e.g., cesarean section
  - tentorial hemorrhage
- Secondary hemorrhage
  - hemorrhagic infarction
  - (vascular) malformation
  - tumor (lipoma), sinus thrombus ...
Hydrocephalus & atrophy

• Posthemorrhagic findings: cysts
• Hydrocephalus
  - echogenic wall after bleed
Hydrocephalus & atrophy

- **Posthemorrhagic findings: cysts**
- **Hydrocephalus**
  - echogenic wall after bleed
  - congenital brain malformation?
    - axial approach
    - occipital scan
    - AVM? - CDS
Hydrocephalus & atrophy

- Posthemorrhagic findings: cysts
- Hydrocephalus
  - echogenic wall after bleed
  - congenital brain malformation?
    - axial & occipital approach, AVM?
- brain pressure & drainage need?
  - eye-US & DDS
Hydrocephalus & atrophy

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- Hydrocephalus
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  - brain pressure & drainage need?
    - eye-US & DDS
- DD: atrophy, subdural collection
Hydrocephalus & atrophy

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- Hydrocephalus
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  - congenital brain malformation?
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- DD: atrophy, subdural collection

= follow-up essential
  - for clinical course & DD (other cysts ...)

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US criteria in brain malformations

• Usually diagnosed prenatally
  - postnatal confirmation + follow-up + exact diagnosis
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• US-aspects:
  - corpus callosum
    + septum pellucidum?
  - CSF spaces
  - posterior fossa!
US criteria in brain malformations

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- US-aspects:
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    + septum pellucidum?
  - CSF spaces
  - posterior fossa!
  - brain parenchyma => HR-US
    - gyration? heterotopia? ...
Other & unusual views / access

• **Occipital & nuchal**
  - posterior horn & posterior fossa
Other & unusual views / access

• Occipital & nuchal
  - posterior horn & posterior fossa

• Transtemporal + axial
  - great vessels + DDS / CDS
    • comparison, ...
  - brain stemm
  - extra-axial collections
Other & unusual views / access

• Occipital & nuchal
  - posterior horn & posterior fossa

• Transtemporal + axial
  - great vessels + DDS / CDS
    • comparison, ...
  - brain stemm
  - extra-axial collections

• Older children
  - fontanella closed => allways TCI
Modern US - HI in the brain

Transfontanellar US

• improved border definition
Modern US - HI in the brain

Transfontanellar US

• improved border definition

• depiction of focal lesions
  - tumors, edema, abscess, ...
  - hemorrhage, ...

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Modern US - HI in the brain

Transfontanellar US

- improved border definition
- depiction of focal lesions
  - tumors, edema,
  - hemorrhage, abscess, ...
- delineation of liquid structures
  - hydrocephalus, cysts, ...
  - shunt, ...
What about Doppler sonography

= established + helpful tool
  - allows for functional evaluation
  - not achievable by any other method

• Fontanellar approach
  - always use also duplex Doppler
  - perform spectral analysis
What about Doppler sonography

= established + helpful tool
  - allows for functional evaluation
  - not achievable by any other method

• Fontanellar approach
  + transtemporal CDS
What about Doppler sonography

= established + helpful tool
  - allows for functional evaluation
  - not achievable by any other method

• Fontanellar approach
  + transtemporal

• Many indications
  - vessel anatomy
  - brain perfusion
  - DD liquid - vascular
e.g., Asphyxia

Typical development:
- initially normal
- then hyperemia
  => RI normal or ↓
e.g., Asphyxia

Typical development:
- initially normal
- then hyperemia
  => RI normal  or \( \downarrow \)
- increase in resistance
  => \( V_{\text{diast}} \) reduced  => RI = \( \uparrow \)
  • then \( V_{\text{syst}} \) \( \downarrow \)
  • tent shaped diastoly
e.g., Asphyxia

Typical development:
- initially normal
- then hyperemia
  => RI normal or \(\downarrow\)
- increase in resistance
  => \(V_{\text{diast}}\) reduced => RI = \(\uparrow\)
  • then \(V_{\text{syst}}\) \(\downarrow\)
  • tent shaped diastoly
  • diastolic flow reversal
- undulating blood => no sufficient perfusion, brain death
Older children => query brain death?

- After every cerebral hypoxia, using TCI
  - drowning, ...
  - bed side evaluation
DS in brain pressure

• Flow pattern change with intracranial pressure
  - basic-DDS => normal?
  - extracranial flow pattern?
    - $V_{syst}$, $V_{diast}$, RI ...
  - standardized ACI-DDS
    - flow velocities increase with pressure
    - difference extra- & intracranial portion
DS in brain pressure

• Flow pattern change with intracranial pressure
  - basic-DDS => normal?
  - extracranial flow pattern?
    • $V_{syst}$, $V_{diast}$, RI
  - standardized ACI-DDS
    • flow velocities increase with pressure
    • difference extra- & intracranial
    • for velocity measurements:
      ALWAYS apply angle correction
DS in brain pressure

• Flow pattern change with intracranial pressure
  - basic-DDS => normal?
  - extracranial flow pattern?
    • $V_{syst}$, $V_{diast}$, RI
  - standardized ACI-DDS
    • flow velocities increase with pressure
    • difference extra- & intracranial portion
    • angle correction
  - changes with fontanellar compression
    $V_{syst}$ ↓, RI ↑
Functional DDS

- Note: flow pattern change with circulation
  - with head position
    - SIDS
    - DD subclavian steel phenomenon
Functional DDS

• Note: flow pattern change with circulation
  - with head position
    • SIDS, DD subclavian steel
  - pCO2
    • respirator settings ...
Functional DDS

- Note: flow pattern change with circulation
  - with head position
    - SIDS, DD subclavian steel
  - pCO2
    - respirator settings
  - tachycardia
    - bradycardia ...
  - medication
    - cathecholamine, RR- drugs & inotrop medication., ...
Specific applications

• \textsc{aCDS}: less angle dependency

• Peripheral vasculature
  - arteries & veins
Specific applications

- **aCDS**: less angle dependency
- **Peripheral vasculature**
  - arteries & veins
- **Liquor flow**
  - if CSF particles present
Specific applications

- **aCDS**: less angle dependency
- **Peripheral vasculature**
  - arteries & veins
- **Liquor flow**
  - if CSF particles present
- **DD of structures**
  - tumor
  - SDH versus atrophy
Other findings

Brain US may give the clue to diagnosis

• Look for these findings
• Use all options
  - infection & abscess
  - syndromatic disease
Other findings

Brain US may give the clue to diagnosis

• Look for these findings
• Use all options
  – infection, abscess, syndromes
  – necrosis, ...
Don't forget

- Documentation
  - measurements: $V_{syst}$, $V_{end\,diast}$, RI, TAV
  - angle correction (> 20°)
  - peripheral + central vessels
Don't forget

• **Documentation**
  - measurements: $V_{syst}$, $V_{end.dia}$, RI, TAV
  - angle correction (> 20°)
  - peripheral + central vessels

• **Arteries** ACA, ACI, ACM, ACP, AB
  - including axial assessment
  - aCDS may be helpful (TCI)
Don't forget

• Documentation
  - measurements: $V_{\text{syst}}, V_{\text{end.dia.st}}, \text{RI, TAV}$
  - angle correction ($> 20^\circ$)
  - peripheral + central vessels

• Arteries ACA, ACI, ACM, ACP, AB
  - including axial assessment
  - aCDS may be helpful (TCI)

• And veins!!
  - V. Galeni, sup. sag. sinus, deep sinus, …
Echo-enhanced US of the brain

- Rare indications in neonates
  - DD: Tu versus blood clot (i.v. ce-US)
  - => increased conspicuity
Echo-enhanced US of the brain

- **Rare indications in neonates**
  - DD: Tu versus blood clot (i.v. ce-US)
    => increased conspicuity
  - *intraluminal* application
    *complicated hydrocephalus*
Brain ee-US in older children

- Improve visualization
  => see vessels
Brain ee-US in older children

- Improve visualization
  => see vessels
  = capability to analyze
    angle correction ...
Brain ee-US in older children

• **Improve visualization**
  => see vessels
  = capability to analyze

• **Indications**
  - brain perfusion
    • after hypoxia
    • in tumors
  - vascular malformation
    • follow-up
Finally: spinal US

• Established in the neonatal & infant spine

• Prerequisites:
  - high resolution linear Tx
Finally: spinal US

- Established in the neonatal & infant spine
- Prerequisites:
  - high resolution linear Tx
  - experience
  - knowledge, training
- helpful accessories:
  - image compounding
  - split (double) image, m-mode
Finally: spinal US

- Established in the neonatal & infant spine
- Prerequisites:
  - high resolution linear Tx
  - experience
    - knowledge, training
  - helpful accessories:
    - image compounding
    - split (double) image, m-mode
    - extended field of view = panorama US
US technique

• Dorsal approach
  - prone or decubitus position
  - blanket? pillow?
    • neck slightly bent (occipital view)
US technique

• **Dorsal approach**
  - prone or decubitus position
  - blanket? pillow?
    • neck slightly bent (occipital view)

• **Start sacral**
  - continue upwards
US technique

• Dorsal approach
  - prone or decubitus position
  - blanket? pillow?
    • neck slightly bent (occipital view)

• Start sacral
  - continue upwards

• Use unusual approach
  - ventral / transabdominal
  - fill bladder / colon
Extended US examination

• **Use modern techniques**
  - m-mode, extended field of view, 3DUS

• **Know anatomy**
  - normal variants
Extended US examination

• Know anatomy & use modern techniques
  - normal variant? m-mode, extended view, 3DUS

• Visualization of cranio-cervical junction
  - herniation of tonsils?
  - curved / sector array
Extended US examination

• Know anatomy & use modern techniques
  - normal variant? m-mode, extended view, 3DUS

• Visualization of cranio-cervical junction
  - herniation of tonsils?
  - curved / sector array

• If spinal pathology present
  + brain US
  - associated malformation? Hydro?
  - transfontanellar, transtemporal, …
Normal US findings
Other important US indications

- **Skull fracture**
  - linear array, hematoma?
  - look for tear drop lesions!
**Other important US indications**

- **Extra-axial hemorrhage?**
  - you may try US (axial!)
  
  If unclear, SAH (tentorial) ...
  
  => CT!
Other important US indications

• Skull fracture
  - linear array, hematoma?
  - look for tear drop lesions!

• Extra-axial hemorrhage?
  - you may try US (axial!!)
  - tentorial, unclear, SAH => CT?

• DD of uncertain (spine & brain) lesions
  - aCDS, axial view, move, ce-US, ...
Other important US indications

• Skull fracture
  - linear array, hematoma?
  - look for tear drop lesions!

• Extra-axial hemorrhage?
  - you may try US (axial!!)
  - tentorial, unclear, SAH => CT?

• DD of uncertain (spine & brain) lesions
  - aCDS, axial view, move, ce-US, => MRI ...
When to use which modality?

• **Indications for skull film:**
  - fracture & trauma
  - premature synostosis
  - skull defects ...
When to use which modality?

• **Indications for skull film:**
  - Fracture, trauma, premature synostosis, defects, ...

• **CT:**
  - unclear US findings
  - acute severe (multiple) trauma
  - calcifications
  - bone pathology
  - **CT-angiography**
  - if no MRI available
When to use which modality?

- **Indications for skull film:**
  - fracture & trauma, premature synostosis, defects, ...

- **CT:**
  - acute trauma, calcifications, ..
  - bone pathology, CT-angiography
  - if no MRI available

- **MRI:**
  - malformations (heterotopia, gyration ...)
  - metabolic disorders, ...
  - asphyxia, trauma (late phase) / battered child, tumor ...
Imaging algorithms

• **Impact on therapy or prognosis**
  = „evidence based“

• **Patient oriented**
  - adapted to local circumstances

• **As little invasive / ionising as possible**
  - **ALARA** - principle

• No examination without valid indication
  e.g., if US cannot answer query => **CT / MR, NO US**
e.g., birth trauma

• What do we expect, what can we treat?
  - asphyxia
  - hemorrhage
    • tentorial, dural
e.g., birth trauma

• What do we expect, what can we treat?
  - asphyxia
  - hemorrhage
  - fractures / epiphysiolyisis
    • plain film
      • chest, clavicle, ...
    • US => epiphysis
e.g., birth trauma

- What do we expect, what can we treat?
  - asphyxia
  - hemorrhage
  - fractures / epiphysiolysis
    - plain film (chest, clavicle, ...)
    - US => epiphysis
  - spinal trauma
    US = initial imaging
    - bed side

=> MRT! (delayed)
Take away

Modern US of the neonatal brain and spine

- holds great diagnostic potential
  - though not yet all approaches & methods established
Take away

Modern US of the neonatal brain and spine

• holds great diagnostic potential
  - though not yet all approaches established

• improves already established value
  - & documentation

• provides valuable information

Modern US = valuable adjunct to conventional 2DUS
Better ask me - otherwise I shall ask you ...!
Thank You!