Brain Injury
Healthcare Technology Co-operative

National Institute for Health Research

Neonatal neurocritical care – finding and filling the gaps

Workshop facilitated by the Institute for Manufacturing, Education and Consultancy Services, Cambridge, 24 May 2016

The NIHR Brain Injury Healthcare Technology Co-operative is delivered in partnership between Cambridge University Hospitals NHS Foundation Trust and University of Cambridge

Contents

1. Workshop summary

This half-day workshop was designed to explore ways to improve outcomes across the patient journey, create outline ideas for future research and service-development projects, and encourage wider collaboration between brain injury professionals and service providers in these projects. Led by the University of Cambridge Institute for Manufacturing Education and Consultancy Services (IfM ECS), the workshop employed a 'fast-pass' version of the IfM landscaping methodology.

Delegates identified targets for reducing costs and achieving earlier diagnosis as key drivers. To provide the evidence-base required to support the introduction of novel solutions and approaches to meet these targets, the establishment of a neonatal early-stage research network to enable access to data on rare conditions was discussed and agreed as an important primary step. The patient pathway experience is characterised by extensive monitoring but limited real-time analysis (e.g. no comprehensive big data analysis or machine learning technology). A notable challenge is the absence of automated early diagnosis of seizures. A key enabler/resource identified is an ongoing trial focussed on the automatic detection of seizures in term babies. A further challenge is that research is not seen as an essential part of the patient pathway.

Delegates' vision for neonatal neurocritical care envisages a new set of drivers and trends:

- Wearable technology
- 3D printing
- Creation of well-annotated multi-centre database of high-fidelity monitoring data
- Automated sleep analysis on ICU to improve neurodevelopment

In this vision, the patient pathway experience is characterised by individualised bedside monitoring and information management as well as efficient use of repurposed drugs for rare neurological disorders. Associated enablers and resources include wearable imaging technologies for continuous monitoring of optical, ultrasound electroencephalography (EEG), (MRI eventually) and ultimately artificial intelligence and computer vision (3D) for continuous monitoring.

Five potential projects were proposed for further development:

- Real-time video monitoring for parents
- Individualised management of preterm infants in neonatal neurocritical care based on real-time multimodal monitoring
- Continuous EEG monitoring for early seizure diagnosis
- Neuroprotection
- Sleep measurement

Table 1 (page 4) summarises key details of the selected opportunities.

Delegates found the workshop stimulating, enjoyable and insightful. Next steps are review and development of the five potential project opportunities in order to apply for grant funding.

Title	Opportunity offers…	Benefits	Key actions
Real-time video monitoring for parents	Deeper parental involvement in neonatal care	The need to promote parental well-being and family bonding. Addresses: • increased parental anxiety • physical barriers (travel, family commitments, disability/ health) At the same time enables neurodevelopmental care (newborn behaviours and communication, sleep) and teaching and research and clinical management	• Seek ethical approval (incorporate other potential uses of data, i.e. teaching, clinical, research, legal) • Seek financial support, i.e. NIHR (equip. + IT support); DLISS/ SPARISS • Data storage and management (accessibility) • Education of staff and parents • Consider management of acute scenarios/time delay and how to manage resuscitation, audio captured Cost of data storage (how to manage the data?)
Individualised management of preterm infants in neonatal neurocritical care based on real-time multimodal monitoring	A methodology for integrating, interpreting and exploiting (in real time) multimodal neuro-monitoring data for preterm infants	• Improved outcome using individualised strategy based on real-time multimodal monitoring • Decreased burden of preterm birth on individual, families, society, economy	• Data collection network with centralised database of high-resolution, high-fidelity data • Established clinical annotation paradigm • Expert system(s) for real-time classification of severity of injury, early warning indicators • New hardware if required
Continuous EEG monitoring for early seizure diagnosis	Objectively detect seizures, predict their onset and improve neurodevelopmental outcomes	A cumulative effect across the life- span of individual • Create evidence base for best treatment	• Identify networks • Identify mature technologies • Fluid funding for consortium
Neuroprotection	Reduce the number of children with brain damage	• We can identify some types of injury at a time when it can be treated • Improve outcomes and reduce suffering	• Add therapy to hypothermia e.g. EPO • Possible therapy for preterm e.g. SMA • Personalised medicine for rare genetic disorders • Images, genetics, delivery, trials, laboratory investigation
Sleep measurement	Improve infants sleep on the NICU: 'Chronomedicine is the future'	• Poor quality sleep is associated with adverse outcomes at all ages • This is particularly true for the developing brain, making millions of neuronal connections (or not) on the NICU	• Develop multimodal wearable technologies • Study the impact of sleep (or lack of) in infants on the NICU • Provide a robust evidence base to commercialise this technology across NICU and beyond

Table 1 Key details of selected opportunities for further development *Neonatal neurocritical care workshop*, NIHR Brain Injury Healthcare Technology Co-operative, 24 May 2016

2. Aims, objectives and approach

2.1 Aims and objectives

This event was designed to enable the NIHR Brain Injury Healthcare Technology Co-operative (HTC) to explore gaps in the area of neonatal neurocritical care, and identify opportunities for enabling projects to address those gaps. Its objectives were to:

- Determine if healthcare technologies can help improve outcomes across the patient journey in the neuro neonatal intensive-care unit ('neuroNICU')
- Create outline ideas for future research and service development projects
- Encourage wider collaboration between HTC, brain-injury professionals and service providers in these projects

2.2 Approach

Preparation and participation

The workshop on 24 May 2016 brought together 16 delegates representing a cross-section of those involved in the patient pathway, for an interactive five-hour programme. A list of delegates is shown in appendix 1 (page 21).

Developing the landscape

In the first part of the workshop, delegates developed a 'neonatal neurocritical care landscape', building on individual preparatory work. The landscape development enabled identification of key topics, out of which potential opportunities for research and enabling projects were explored.

The landscaping process was based on the following questions:

- Why do we need to take action (particularly as regards developing needs)?
- How can the patient pathway experience be developed to respond to those needs?
- What enabling projects and resources are required to deliver that pathway experience?

IfM's landscaping process employs individual reflection, group discussion and voting to generate information and ideas, captures and develops these on a large wallchart (the visual format highlighting potential gaps, links, opportunities and challenges), then ranks by voting. The three layers of the landscape are aggregated to identify linkages and clusters (on a 'linkage chart') and hence possible priorities for action. In this 'fast-pass' version of the process delegates, having prepared their individual narratives, presented their key perspectives directly onto all three layers of the landscape in a series of 2–3 minute 'pitches'.

Prioritising the findings

Delegates collectively reviewed the importance of the items identified then voted on priorities for each layer. The facilitator and client-lead then proposed which themes to investigate.

Having identified a number of priority opportunities by this method, delegates formed syndicate groups, each to develop one outline research or enabling project, using a 'project proposal exploration' template. In the final session, syndicates presented their findings for whole-group review.

Overview of approach

Figure 1 illustrates the workshop approach. Subsequent sections of this report outline the main outputs from the process.

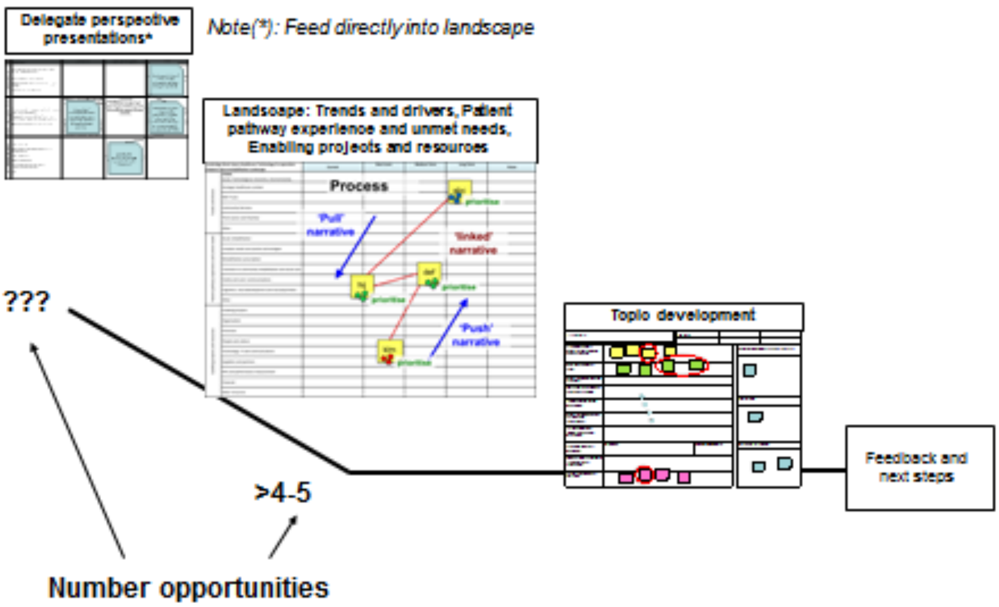

Figure 1 Process employed, Neonatal neurocritical care workshop, NIHR Brain Injury Healthcare Technology Co-operative, 24 May 2016, showing templates for individual reflection, whole-group landscape development and syndicate work for topic development.

3. Landscape development

The figures below summarise the key elements of the landscape (figure 2) and associated linkage chart (figure 3).

Brain Injury
Healthcare Technology Co-operative

NHS
National Institute for
Health Research

Cambridge Brain Injury Healthcare Technology Co-operative: Neonatal neurocritical care landscape		**Current 2016**	**Short term 2016–17**	**Medium term 2018–20**	**Long term 2020–25**	**Vision 2025+**
Trenda and drivers	**STEEPL** Social, Technological, Economic, Environmental, Political, Legal developments				Wearable technology 3D printing	
	Strategic healthcare context	Targets for reducing costs and achieving earler diagnosis		Complex cases require a synthesis of complex data in real time		
	NHS		Neonatal early stage research network to enable access to rare conditions		Creation of well-annotated multi-centre database of high-fidelity monitoring data Automated sleep analysis on ICU will improve neurodevelopment Early detection of degree of injury/earlier prediction of prognosis	
Patient pathway experience and unmet needs	Identification of the vulnerable/at risk infant			Continuous EEG monitoring of infants at risk	Better identification of preterms at risk	Individualised bedside monitoring and information management
	Condition diagnosis	Extensive monitoring but limited real time analysis (no comprehensive big data analysis or machine learning) Automated early diagnosis of seizures is absent				
	Neuroprotection interventions				Enable efficient use of repurposed drugs for rare neurological disorders	
	Family communications	Research not seen as essential part of patient pathway		Real-time video monitoring of infant for parents		
	Other					
Enabling projects and resources	Enabling projects	Ongoing trial in progress on automatic detection of seizures in term babies		Set up trial in which sleep is promoted to see if it improves outcome		
	Technologies – Biomarkers	No robust method to determine how damaged the newborn injured brain		Use of blood samples to determine the brain injury		
	Technologies – Signal processing/neurophysiology		NIRS technology/signal processing			
	Technologies – Novel/multimodal imaging		Multi-modal data collection to review whether brain metabolism can predict outcome early at cotside		Develop novel early diagnosis technologies for PAIS	
	Technologies – Other				Molecular understanding of tertiary damage Wearable imaging technologies for continuous monitoring of optical, ultrasound EEG, (MRI eventually) Artificial intellegence and computer vision (3D) for continuous monitoring	

Figure 2 Neonatal neurocritical care landscape, NIHR Brain Injury Healthcare Technology Co-operative workshop, 24 May 2016

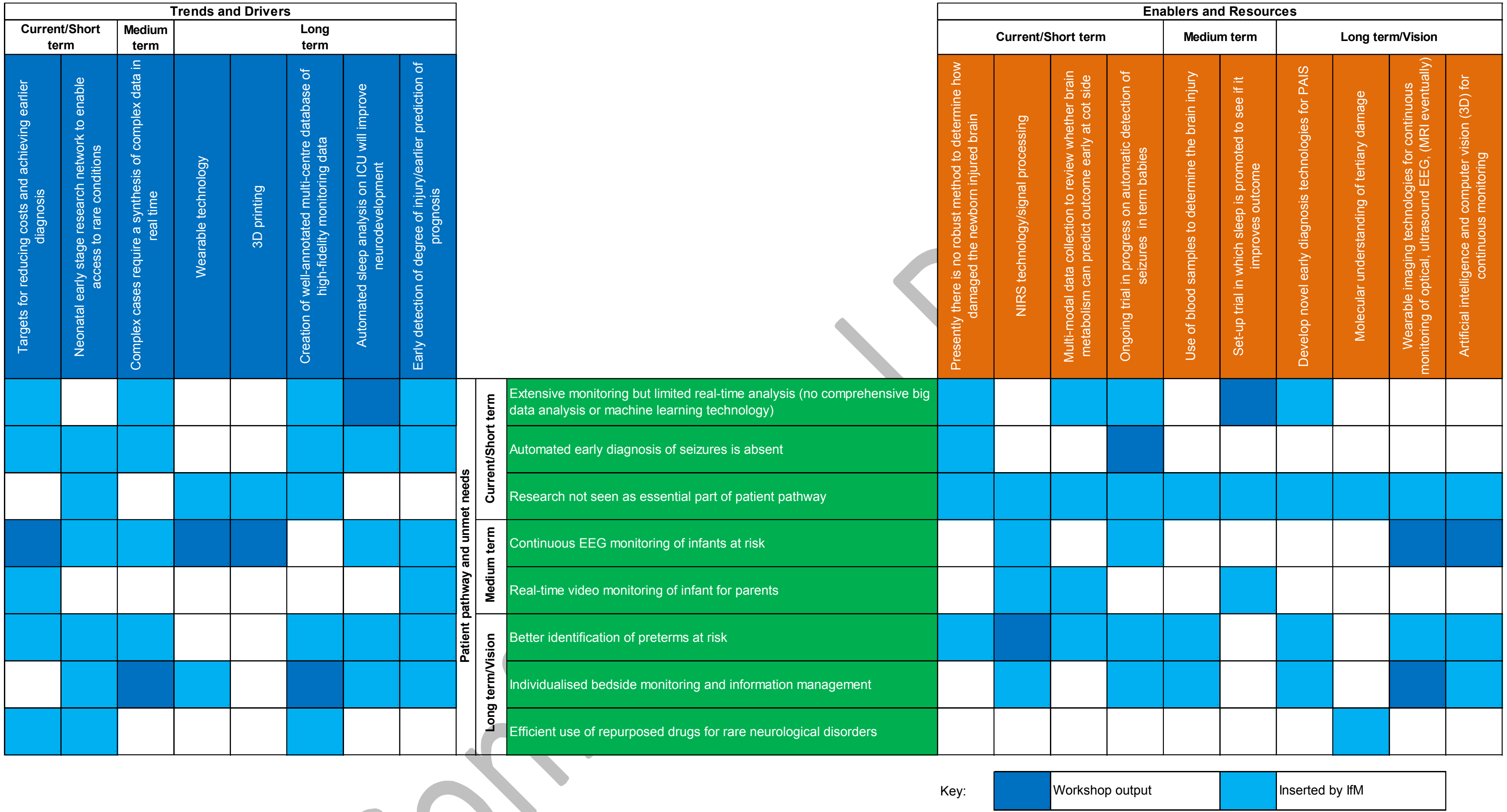

Figure 3 Neonatal neurocritical care linkage chart, NIHR Brain Injury Healthcare Technology Co-operative workshop, 24 May 2016

The linkage chart visualises relationships between patient pathway experiences/unmet needs and a) trends and drivers and b) enabling projects and resources. It is largely derived from information and ideas contributed by delegates (shown as dark-blue squares), but also includes linkages added retrospectively by IfM (light-blue squares).

Appendix 2 (page 22) lists the full output relating to 1. Trends and drivers, 2. Patient pathway experience and unmet needs, and 3. Enabling projects and resources, showing delegate views of the importance and timeframe attached to each item.

4. Selected topic development

Tables 2–6 below show the topic development outputs as explored by delegates in syndicate groups:

- Real-time video monitoring for parents
- Individualised management of preterm infants in neonatal neurocritical care based on real-time multimodal monitoring
- Continuous EEG monitoring for early seizure diagnosis
- Neuroprotection
- Sleep measurement

4.1 Real-time video monitoring for parents

Proposed project: What problem are we going to solve?	Parental involvement in neonatal care	**Team members:** Kelly Spike, Ping Yip and Maria Chalia
Why should we do this?	• Parents are sometime unable to visit their babies (because of distance, siblings, twins) • Increased maternal depression in the NICU (and dads!) • Enable bonding, attachment and closeness (reduce anxiety?) • Help clinical diagnosis in certain infants • Neurodevelopmental teaching/care; NIDCAP; newborn behaviour and communication; sleep • For research and teaching purposes	**We have a need/opportunity for:** Deeper parental involvement in neonatal care
What is the scale of the problem?	Every neonate; neonatal networks	
Required outcome and timing to complete	Ethics; allow parental option (facetime instead); NHS computing facilities	
Staged deliverables and dates	Now	**Because:** • The need to promote parental well-being and family bonding • Increased parental anxiety • Physical barriers (travel, family commitments, disability/ health) • At the same time enable neurodevelopmental care (newborn behaviours and communication, sleep) and teaching and research and clinical management
What is missing today, for example information?	No video monitoring	
Current relevant research and other activities	• Chip subcutaneous implant (motion detection and temperature) for 24-hour monitoring • Infrared 24-hour monitoring (esp. during night)	

<table>
<tr><td>Key actions (including proposed team to address)</td><td>Actions: Ethical approval to video for parental, clinical, legal and research; Data protection (pass-worded and encrypted?). Education of staff and parents on how to use equipment (password protected)</td><td>Team members: Consultant in charge of managing monitoring neuroimaging devices with IT support & neurodevelopmental care sister</td><td rowspan="3">Actions to deliver:
Seek ethical approval (incorporate other potential uses of data, i.e. teaching, clinical, research, legal)
Seek financial support, i.e. NIHR (equip. + IT support); DLISS/ SPARISS
Data storage & management (accessibility)
Education of staff & parents
Consider management of acute scenarios/time delay and how to manage resuscitation, audio captured
Cost of data storage (how to manage the data?)</td></tr>
<tr><td>Resource requirements (financial and manpower)</td><td colspan="2">Equipment/finance – video recorders per cot; online system</td></tr>
<tr><td>Other enablers and barriers</td><td colspan="2">Audio capture? Output might be used for legal proceedings; acute scenarios or procedures (time delay?, witness or not to witness?); could increase parental anxiety; on-going data storage (1hr of recording is ~ 9,000,000MB)</td></tr>
</table>

Table 2 Topic development *Real-time video monitoring for parents*. Neonatal neurocritical care workshop, NIHR Brain Injury Healthcare Technology Co-operative, 24 May 2016

4.2 Individualised management of preterm infants in neonatal neurocritical care based on real-time multimodal monitoring

Proposed project: What problem are we going to solve?	Early warning system based on multimodal neuro-monitoring system in preterm infants for improved outcome Problem: inability to utilise the multimodal monitoring for improving preterm neuro-critical care	**Team members:** Peter Smielewski, Subha Mitra and Rob Cooper
Why should we do this?	• Preterm birth in association with significant morbidities, mortalities and neuro-developmental outcome • Increasing prevalence of preterm birth • Huge economic and social cost	**We have a need/opportunity for:** A methodology for integrating, interpreting and exploiting (in real time) multimodal neuro-monitoring data for preterm infants
What is the scale of the problem?	£4 billion a year	
Required outcome and timing to complete	• Multicentre research programme with centralised data analysis • Large multimodal longitudinal dataset with clinical annotation • Expert systems of annotated identification and clarification of injury severity and secondary insults	
Staged deliverables and dates	• Unified local data collection system (hardware and software) • Centralised data collection infrastructure; clinical annotation paradigm; data collection phase • Data analysis; data validation (new hardware)	**Because:** Improved outcome using individualised strategy based on real-time multimodal monitoring to decrease burden of preterm birth on individual, families, society, economy
What is missing today, for example information	• Active involvement of clinicians with real-time annotation • Standardisation	
Current relevant research and other activities	• EEG & seizure (Cork) • Adult TBI data collection analysis projects; Centre-TBI; Track-RBI • Paediatric ADAPT data collection study	

<table>
<tr><td>Key actions (including proposed team to address)</td><td>Actions: Establishing care team
Training/standardisation</td><td>Team members:</td><td rowspan="3">Actions to deliver:
• Data collection network with centralised database of high-resolution, high-fidelity data
• Established clinical annotation paradigm
• Expert system(s) for real-time classification of severity of injury, early warning indicators
• New hardware if required</td></tr>
<tr><td>Resource requirements (financial and manpower)</td><td colspan="2">• Significant resource requirement
• Funding for data collection systems ; data collection investigators; centralised database
• integration & management; data analysis; rolling out expert system for validation; and prototypes</td></tr>
<tr><td>Other enablers and barriers</td><td colspan="2">Ethics; reliable annotation (standardised); cannot pilot!; objective reliable outcomes</td></tr>
</table>

Table 3 Topic development *Individualised management of preterm infants in neonatal neurocritical care based on real-time multimodal monitoring*. Neonatal neurocritical care workshop, NIHR Brain Injury Healthcare Technology Co-operative, 24 May 2016

4.3 Continuous EEG monitoring for early seizure diagnosis

Proposed project: What problem are we going to solve?	Continuous monitoring EEG for early seizure diagnosis	**Team members:** Gene Dempsey, John Suckling and Heike Rabe
Why should we do this?	• Prevalence – high impact of intervention; seizures are bad for patients • Opportunity to test a new intervention; dissociation between clinical and electrical seizures • Interference or withdrawal of case/ decision to continue	**We have a need/opportunity for:** • Objectively detect seizures • Predict their onset • Improve neurodevelopmental outcomes
What is the scale of the problem?	Disability long-term outcome	
Required outcome and timing to complete	• Seizure burden reduction • Improve neurodevelopmental outcome	
Staged deliverables and dates	• CE/quality of EEG caps/ other technology; wireless • Trials of various measurement of seizure detection • Trials benchmark performance algorithm/ expert – different credentials/ age group; disease specific • Trial introduce intervention (which one, when?)	**Because:** • A cumulative effect across the life span of individual • Create evidence base for best treatment
What is missing today, for example information	• Analysis of published animal work – uniform human studies? • Meta-analysis; existing publication on seizure burden and neurodevelopmental outcome; wireless technology • EEG caps to put on easily as standard; • Development of 'brain health' index; algorithm for seizure detection; literature reviews on current treatments and their outcomes; integration of risk factors for seizures into decision pathways	
Current relevant research and other activities	• Ongoing study…….seizure detection algorithm; • Ongoing…..on drugs for treating seizures (Bumetanide, Lignocaine)	

Key actions (including proposed team to address)	**Actions:** Engage with manufacturers (CE) – regulating approvals; engage with groups developing algorithm	**Team members:**	**Actions to deliver:** • Identify networks • Identify mature technologies • Fluid funding for consortium
Resource requirements (financial and manpower)	• Funding – HTA/, William Trust, EC; steering groups • Patient or parent involvement		
Other enablers and barriers	• Collaboration with… • Treatment existing; mechanical materials; EUBC; learned societies; WC seizure group		

Table 4 Topic development *Continuous EEG monitoring for early seizure diagnosis.* Neonatal neurocritical care workshop, NIHR Brain Injury Healthcare Technology Co-operative, 24 May 2016

4.4 Neuroprotection

Proposed project: What problem are we going to solve?	• Rare/genetic regenerative in NICU • Preterm; term – (HIE/stroke)	**Team members:** David Rowitch, David Edwards and Divyen Shah
Why should we do this?	• Improve outcome; economic; reduce suffering	**We have a need/opportunity for:** Reduce the number of children with brain damage
What is the scale of the problem?	Collectively, large	
Required outcome and timing to complete		
Staged deliverables and dates	• Inflammatory: Reduce BBB leak; reactive astrocytes; microglia-nano particles • Genomics: injury pathways; extreme phenotype; rare disorders • Follow up: EMR; clinic for severe outcome (CP, IDD) • Delivery: convention; IV-BBB; direct (cells) • Small molecule; ERT; gene; cells; gas	**Because:** • We can identify some types of injury at a time when it can be treated • Improve outcomes and reduce suffering
What is missing today, for example information	All of the above	
Current relevant research and other activities	• Diagnostic imaging • Animal models; human neuropathology • Human cell-based models	

Key actions (including proposed team to address)	**Actions:** Lead compounds; injury – SAG, EPO; rare – MPS7, Tay Sachs - identify cohorts across regions	**Team members:**	**Actions to deliver:** • Add therapy to hypothermia e.g. EPO • Possible therapy for preterm e.g. SMA • Personalised medicine for rare genetic disorders • Images, genetics, delivery, trials, laboratory investigation
Resource requirements (financial and manpower)	Full assessment required, but significant resource likely		
Other enablers and barriers	Patient advocates/engagement		

Table 5 Topic development *Neuro protection*. Neonatal neurocritical care workshop, NIHR Brain Injury Healthcare Technology Co-operative, 24 May 2016

4.5 Sleep measurement

Proposed project: What problem are we going to solve?	Improved quality of sleep in infants on NICU; lack of/interrupted sleep – poor brain development	**Team members:** Jeroem Dudnick, Jeremy Hebden and Topun Austin
Why should we do this?	Problem affects all patients in the ICU (of any age!)	**We have a need/opportunity for:** Improve infants' sleep on the NICU: 'Chronomedicine is the future'
What is the scale of the problem?	Problem affects all patients in the ICU (of any age!)	
Required outcome and timing to complete	Technologies to monitor motion – motion sensors, infrared sensors, EMG sensor 1. Bring in all the monitoring technologies (identify the optimal way of measuring sleep) 2. Develop a wearable device, integrating the technologies identified in (1.)	
Staged deliverables and dates	Technologies to measure sleep – circadian rhythm, EEG/ a EEG, melatonin?, cortisol?	**Because:** • Poor quality sleep is associated with adverse outcomes at all ages • This is particularly true for the developing brain, making millions of neuronal connections (or not) on the NICU
What is missing today, for example information	• Tailor care and management according to sleep e.g. feeding, drugs (n.b. caffeine) • Technology - wearable, cameras, integrated data analysis • Undertake meaningful research into sleep quality outcome	
Current relevant research and other activities	• Research impact of sleep on developing brain • Improved sleep • Improved outcomes	

Key actions (including proposed team to address)	**Actions:** Develop the required technologies	**Team members:**	**Actions to deliver:** • Develop multimodal wearable technologies Study the impact of sleep (or lack of) in infants on the NICU • Provide a robust evidence base to commercialise this technology across NICU and beyond
Resource requirements (financial and manpower)	A large grant is likely to be required		
Other enablers and barriers	Challenge of undertaking meaningful research given what is perceived to be an inherent bias among nursing staff		

Table 6 Topic development *Sleep measurement*. Neonatal neurocritical care workshop, NIHR Brain Injury Healthcare Technology Co-operative, 24 May 2016

5. Feedback and next steps

Delegate feedback as given via the end-of-workshop questionnaire is summarised in appendix 3 (page 26).

All delegates felt they were able to contribute, found the workshop stimulating, enjoyable and worthwhile and thought that it provided useful insights. The workshop process and structure were judged as good.

Some delegates felt that broadening workshop participation to include, if possible, education and patient/parent representatives would have been beneficial.

There were some concerns about temperature control in the venue.

This report of the workshop is a draft for circulation, to invite comments from delegates before finalisation. Following finalisation of the report delegates will be invited to contribute to further development of the identified opportunities in order to support application for grant funding.

Appendices

Appendix 1: Workshop delegates

Delegates:

1. Dr Topun Austin, Consultant Neonatologist, Cambridge University Hospitals
2. Dr Rob Cooper, Department of Medical Physics and Biomedical Engineering, University College London
3. Professor Gene Dempsey, Professor of Neonatology, University College Cork
4. Dr Jeroem Dudnick, Neonatologist, Sophia Children's Hospital, Rotterdam
5. Professor David Edwards, Professor of Neonatology, King's College London
6. Professor Jeremy Hebden, Head of Department of Medical Physics and Biomedical Engineering, University College London
7. Maria Chalia, Clinical Research Fellow, Cambridge University Hospitals
8. Professor Heike Rabe, Professor of Neonatology, Brighton and Sussex Medical School
9. Subha Mitra, Clinical Research Fellow, University College London
10. Dr Rob Ross-Russell, Consultant Paediatrician, Cambridge University Hospitals (a.m. only)
11. Professor David Rowitch, Head of the Department of Paediatrics, University of Cambridge
12. Dr Divyen Shah, Consultant Neonatologist, Royal London Hospital
13. Dr Peter Smielewski, Senior Research Associate, Department of Clinical Neurosciences, University of Cambridge
14. Ms Kelly Spike, Neonatal Neurocritical Care Nurse Specialist, Cambridge University Hospitals
15. Professor John Suckling, Director of Research, Department of Psychiatry, University of Cambridge
16. Dr Ping Yip, Lecturer in Neurotrauama, Queen Mary, University of London

Facilitators:

Andrew Gill, Principal Industrial Fellow, IfM Education and Consultancy Services, Cambridge

Steve Chicken, Principal Industrial Fellow, IfM Education and Consultancy Services, Cambridge

Also supporting:

Peter Jarrett, Deputy Director of the Brain Injury HTC

Mita Brahmbhat, Programme Manager of the Brain Injury HTC

Talissa Gasser, Programme Coordinator of the Brain Injury HTC

Appendix 2: Workshop outputs showing delegate votes

A2.1 Trends and drivers

Swim lane	Description	Votes	Timing	Date
STEEPL Social, Technological, Economic, Environmental, Political, Legal developments	Wearable technology	7	long term	n/a
	3D printing	5	long term	n/a
	Autonomous technologies	2	vision	n/a
Strategic healthcare context	Targets for reducing costs and achieving earlier diagnosis	6	short term	n/a
	Complex cases require a synthesis of complex data in real time	6	medium term	2020
NHS	Issues of specialty and research silos/poor access to cardiorespiratory data	2	current	2016
	Fewer children with severe neurocognitive or neuropsychological impairment after term asphyxia	2	vision	n/a
Neonatal networks	Telemedicine for regional and district NICUs	3	short term	2017
	Neonatal early-stage research network to enable better access to data on rare conditions	5	short term	2018
	Creation of well-annotated multi centre database of high-fidelity monitoring data	6	long term	n/a
	Automated sleep analysis on ICU will improve neurodevelopment	7	long term	2019

	Early detection of degree of injury/earlier prediction of prognosis	4	long term	2020
Targets and strategic outcomes and intentions for patient pathway	Need for richer clinical information around preterm brain injury	2	current	2016
	Improved long-term outcomes for preterm infants	3	vision	n/a

Swim lane	Description	Votes	Timing	Date
Identification of the vulnerable/at-risk infant	Continuous EEG monitoring of infants at risk	6	medium term	n/a
	Identify high-risk patients	3	long term	2018
	Better identification of preterm at risk	4	long term	n/a
	Individualised bedside monitoring and information management	7	vision	2025
Condition diagnosis	Extensive monitoring but limited real-time analysis (no comprehensive big-data analysis or machine-learning technology)	4	current	2016
	Need for early diagnosis to enable potential therapies to be developed	3	short term	2016
	Automated early diagnosis of seizures is absent	4	short term	2018
	Measurement of real-time brain metabolism at cot side leading to a novel neuroimaging technique	3	medium term	n/a
Neuroprotection interventions	Efficient use of repurposed drugs for rare neurological disorders	5	long term	2019
Family communications	Research not seen as essential part of patient pathway	4	current	2016
	Real time video monitoring of infant for parents	7	medium term	n/a

A2.3 Enabling projects and resources

Swim lane		Description	Votes	Timing	Date
Enabling projects		Ongoing trial in progress on automatic detection of seizures in term babies	4	short term	end of 2016
Technologies	Biomarkers	No robust method to determine how damaged the newborn injured brain	3	current	n/a
		Use of blood samples to determine the brain injury	3	medium term	2018
	Signal processing/neurophysiology	NIRS technology/signal processing	3	short term	n/a
	Novel/multimodal imaging	Multi-modal data collection to review whether brain metabolism can predict outcome early at cot-side	3	short term	n/a
		Develop novel early diagnosis technologies for PAIS	3	long term	2020
	Other	Molecular understanding of tertiary damage	3	long term	n/a
		Wearable imaging technologies for continuous monitoring of optical, ultrasound EEG, (MRI eventually)	11	long term	2018
		Artificial intelligence and computer vision (3D) for continuous monitoring	7	vision	2025
Organisation, processes, people and culture		Set-up trial in which sleep is promoted to see if it improves outcome	3	medium term	n/a

Appendix 3: Delegate feedback