Review Article

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Early Neurodevelopmental Assessments of Neonates Discharged From the Neonatal Intensive Care Unit: A Physiatrist's Perspective

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The survival rate of children admitted in the neonatal intensive care unit (NICU) after birth is on the increase; hence, proper evaluation and care of their neurodevelopment has become an important issue. Neurodevelopmental assessments of individual domains regarding motor, language, cognition, and sensory perception are crucial in planning prompt interventions for neonates requiring immediate support and rehabilitation treatment. These assessments are essential for identifying areas of weakness and designing targeted interventions to improve future functional outcomes and the quality of lives for both the infants and their families. However, initial stratification of risk to select those who are in danger of neurodevelopmental disorders is also important in terms of cost-effectiveness. Efficient and robust functional evaluations to recognize early signs of developmental disorders will help NICU graduates receive interventions and enhance functional capabilities if needed. Several age-dependent, domain-specific neurodevelopmental assessment tools are available; therefore, this review summarizes the characteristics of these tools and aims to develop multidimensional, standardized, and regular follow-up plans for NICU graduates in Korea.

Keywords: Low birth weight infant, Neonatal intensive care unit, Neurodevelopmental disorder, Premature birth, Rehabilitation

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INTRODUCTION

Recent advances in neonatal care have led to an increase in the survival rates of preterm infants or those with low birth weight in Korea [1]. The average birth weight is declining, and the incidence of preterm births is on the increase [1,2]. Because preterm or low birth weight infants are at high risk of developmental delays or disorders, early and regular assessments of neurodevelopmental outcomes of graduates of neonatal intensive care units (NICUs) should continue immediately after discharge [3]. However, there is significant heterogeneity in the neurodevelopmental assessment follow-up policies in different countries [4]. A variety of development assessment tools are available for each domain and age range; however, a consensus gold standard is still lacking in terms of defining the best neurodevelopmental assessment and follow-up program for the early diagnosis of developmental delay [5,6].

Early identification of infants at high risk of developmental delays or disorders is critical for timely referral for appropriate intervention and family counseling. Proper surveillance of neurodevelopmental outcomes of infants is necessary due to the following: (1) early detection or diagnosis of developmental delay or neurodevelopmental disorders; (2) timely intervention and provision of individualized care within critical periods for better outcomes; (3) to educate family/caregivers regarding the developmental status, prognosis, and any possible problems or dangers of infants to prevent further deterioration; and (4) to improve functional outcomes of these infants and the well-being and quality of life of the entire family. Earlier involvement of parents in the care of babies with neurodevelopmental impairments before hospital discharge from the NICU is known to be effective in improving the parent-infant relationship, providing a nurturing environment, and targeting the intervention for individualized infant and family needs [7]. There should be sufficient parental education on useful and safe home exercises or play, information on proper feeding, positioning, sleep, and any available social services. In the future, these developmental interventions beyond the NICU should be updated with evidence-based intervention techniques for individual diagnoses.

Regular hospital visits for neurodevelopmental assessments after NICU discharge is widely acknowledged; however, there should be a systematic follow-up program for both appropriate diagnosis of neurodevelopmental delay and assessment of the efficacy of developmental interventions [5]. Developmental surveillance programs for NICU graduates should include all domains of neurological, motor, language, cognition, perception, and social skills. Moreover, this program should be encouraged to consider each child's developmental status, caregiver's socioeconomic status, individualized therapeutic program, healthcare resources, and social services or welfare [8,9]. This review summarizes the current evidence of available neurodevelopmental assessment tools for each domain and suggests appropriate Korean surveillance guidelines for NICU graduates.

I. EARLY NEURODEVELOPMENTAL ASSESSMENT PLAN

Developmental surveillance should consider appropriate timing and intervals in terms of cost-effectiveness and availability of healthcare resources. If NICU graduates have more severe risk factors, they would be at an even higher risk of various developmental problems [10-12]. Several risk factors that must be evaluated during NICU stay are summarized in Table 1 for clinicians not to delay neurodevelopmental evaluation for referral to the Department of Pediatric Rehabilitation Medicine. According to the numbers and grades of risk factors (Table 1), a corrected age (CA) to visit for neurodevelopmental surveillance and follow-up periods are suggested in Fig. 1 [3,5,10,13,14].

Early developmental screening is recommended within less than 1 month after discharge if there is at least one high risk factor; any organic brain lesion, such as grade 3 or 4 intraventricular hemorrhage, cystic periventricular leukomalacia, infarction, hypoxic ischemic encephalopathy, neonatal meningitis or encephalitis, and congenital brain malformation, ventriculomegaly, etc.; any feeding disorders associated with malnutrition; neonatal sepsis; bronchopulmonary dysplasia with mechanical ventilation until gestational age of 36 weeks; hyperbilirubinemia; any congenital or neuromuscular disorder, confirmed with gene study; extremely preterm (<28 weeks); extremely low birth weight (<1,000 g); high social risk such as any domestic violence or child abuse, severe poverty or homelessness, no antenatal care provided, caregivers' intellectual disability or psychological problems; any tone abnormality of hyper/hypotonia or fluctuating tones are observed; or a history of infantile spasm or status epilepticus (Table 1). If any neurodevelopmental delay is suspected at the initial immediate follow-up, next follow-up visits or further evaluations should be determined at the physician's discretion according to the individual infant's medical and neurological conditions. Otherwise, later visits can be scheduled as routine follow-ups for low-risk NICU graduates. Further-

Table 1. Risk factor checklist for a surveillance of neurodevelopmental assessment after neonatal intensive care unit discharge

High risk factors
Brain lesion
Grade 3 or 4 intraventricular hemorrhage
Cystic periventricular leukomalacia
Infarction
Hypoxic ischemic encephalopathy
Neonatal meningitis OR encephalitis
Congenital brain malformation, ventriculomegaly, etc.
Any feeding disorders associated with malnutrition
Neonatal sepsis
Bronchopulmonary dysplasia with mechanical ventilation until gestational age of 36 wk
Hyperbilirubinemia (bilirubin >400 μmol/L or clinical evidence of bilirubin encephalopathy)
Diagnosis of genetic or neuromuscular disease (spinal muscular atrophy, myopathy, etc.)
Extremely preterm (less than 28 wk)
Extremely low birth weight (less than 1,000 g)
High social risk (e.g., domestic violence, previous child abuse, severe poverty or homelessness, no antenatal care, intellectual disability or psychologic problem of caregiver, multicultural family)
Tone abnormality (definite hyper- or hypotonia, fluctuating tone)
History of infantile spasm or status epilepticus
Moderate risk factors
Very preterm (28–32 wk) OR very low birth weight: less than 1,500 g
Multiple pregnancy (more than twin, or twin discordance such as a significant birth weight difference in twins)
Known sensory abnormality (hearing, vision [including severe retinopathy of prematurity], etc.)
Small for gestational age: birth weight <10th percentile for gestational age
Major surgery including necrotizing enterocolitis operation (brain, cardiac, thoracic, or abdominal)
Moderate to late preterm (32–37 wk) OR low birth weight: less than 2,500 g
Any clinical event during perinatal period (seizure event, feeding problem etc.)

more, an immediate intervention plan and/or education can be suggested for those with high-risk factors while still in hospital, rather than waiting for a confirmative diagnosis of developmental impairments [3].

Afterwards, moderate risk factors should be screened: very preterm (28–32 weeks) or very low birth weight (1,000–1,500 g) neonates; multiple pregnancies more than twins or discordant twins who show significantly different birth weight between twins; diagnosis of sensory abnormality, such as hearing or visual impairment, and severe retinopathy of prematurity; small for gestational age, that is, birth weight less than 10th percentile for gestational age; major perinatal surgery in the brain, heart, thorax, or abdomen including necrotizing enterocolitis operation; moderate to late preterm (32–37 weeks) or low birth weight (1,500–2,500 g) with any clinical perinatal event like epilepsy or feeding problems (Table 1). If two or more moderate risk factors are present, NICU graduates are required to be followed-up for neurodevelopmental screening within less than 1 month after discharge, similar to the existence of one high-risk factor. On the other hand, if there is only 0–1 moderate risk factor, it is recommended that NICU graduates should have regular checkups at a CA of 3–4 months for the first visit. Thereafter, further follow-up visits for neurodevelopmental assessment are recommended at CA of 8–9 months, 12– 18 months, 24 months, and 36 months (Fig. 1).

However, the follow-up schedule should be refined by clinicians based on the functional and/or medical status of each infant. For example, if any special diagnosis is made, such as genetic or neurodegenerative diseases, the follow-up schedule should be individualized through experts' and multidisciplinary care plans. Although the Bayley Scales of Infant Development (BSID) is an extensive formal developmental assessment tool for diagnosing developmental delays in early childhood for 1 to 42 months old babies (Table 2), it cannot predict long-term outcomes of development, especially when assessed at a young age such as before CA of 24 months old [13,15]. For those still undiagnosed with extremely preterm birth (<28 weeks) or extremely low birth weight (<1,000 g), BSID is strongly recommended at a CA of 36 months. Likewise, individual decision-making regarding which and when each neurodevelopmental assessment tool to choose would enrich better clinical practice and more accurate assessments.

II. OVERVIEW OF NEURODEVELOPMENTAL ASSESSMENT TOOLS

Currently available neurodevelopmental assessment tools are extremely varied at each age band. A regular neurodevelopmental follow-up program should include all developmental domains for more accurate surveillance and diagnosis, including motor, sensory perception, cognition, and language. Irrespective of how comprehensive neurodevelopmental assessment tools are employed, they are often insufficient, and clinicians should decide on additional specialized diagnostic tools for specific domains regarding individual functional status. Based on a comprehensive history taking and physical/neurological examination,

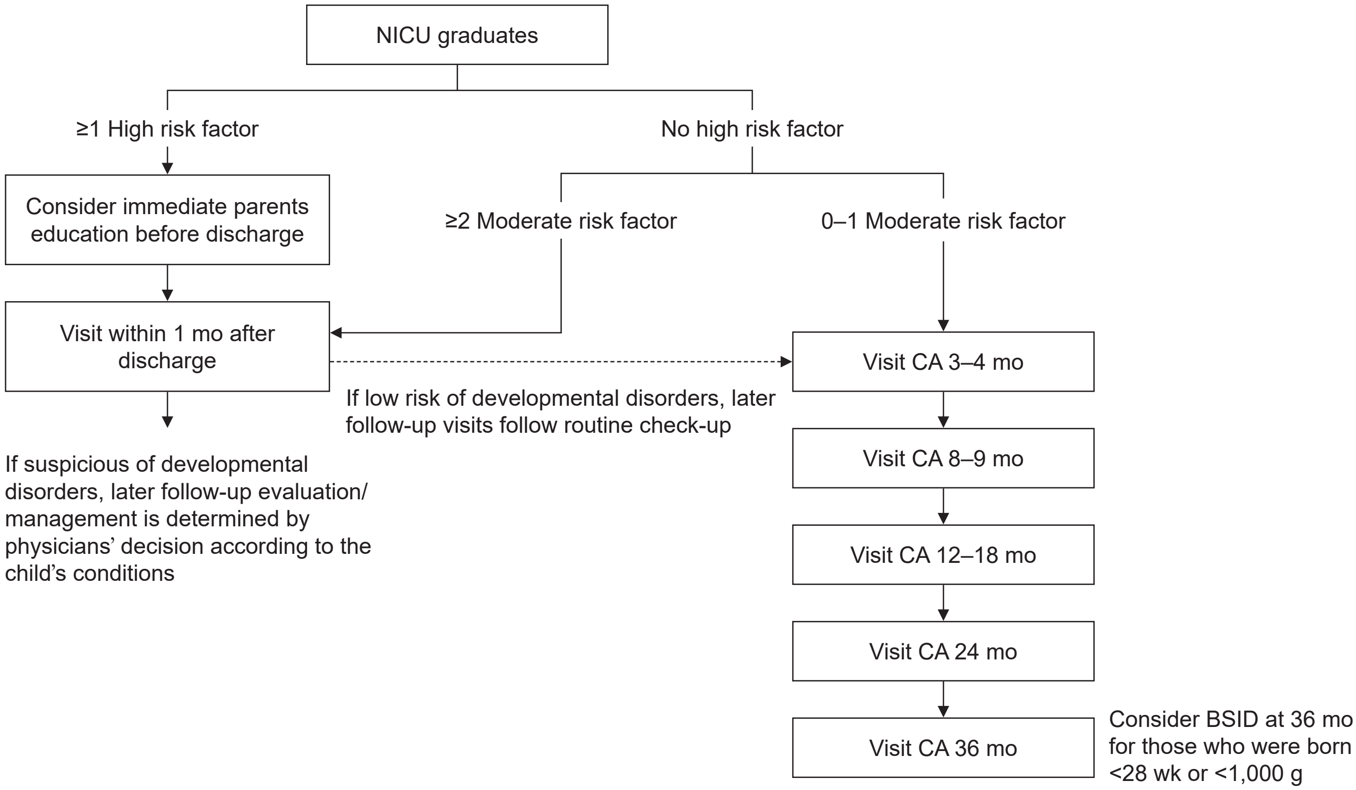

Fig. 1. Neurodevelopmental surveillance and follow-up periods according to risk factors after discharge from neonatal intensive care unit (NICU). CA, corrected age; BSID. Bayley Scales of Infant Development.

including growth, primitive reflexes, postural reactions, developmental history, social/family history, and musculoskeletal evaluation, experienced clinicians should be able to decide any necessary further evaluations, including blood tests, genetic studies, or imaging modalities [5].

Categorical neurodevelopment assessment tools are summarized and compared in detail in Table 2. Each assessment tool is characterized by its target age range, test type characteristic about whether it is norm-referenced based on standard score or criterion-referenced, suggesting a clear-cut cut-off score for diagnosis, evaluation of components within domains, diagnostic criteria, average time to administer, and immediate availability of the Korean-translated version and/or education for evaluators. Among them, the Denver Development Screening Tool (DDST), BSID, Korean-Developmental Screening Test (K-DST), Peabody Developmental Motor Scales (PDMS), Korean-Wechsler Preschool and Primary Scale of Intelligence-IV, and Developmental Test of Visual-Motor Integration-6 (VMI-6) are currently covered by National Insurance in Korea.

Furthermore, currently accumulated evidence on predictive accuracy regarding the reliability, internal consistency, and validity of each development assessment tool is searched and gathered in the Supplementary Tables S1-S4 to help healthcare professionals make a more convenient decision. Reliability is the extent to which patients can be distinguished from normal despite measurement errors and is evaluated through inter-/intra-rater intraclass correlation coefficient (ICC) or Cohen's weighted kappa values. It is "+" if ICC or kappa ≥0.70, "–" for <0.70, and "0" if no available information is found for reliability. Internal consistency is the extent to which items within a domain are inter-correlated to measure the same construct; it is "+" if factor analysis was provided with adequate sample size and Cronbach's alpha values are ≥0.70, "–" if Cronbach's alpha <0.70, and "0" if no available information was found for consistency. Content validity is the comprehensiveness of items in the assessment tools for the domain of interest: "+" if a clear description about the measurement aim, target population, and item selection while target population and evaluators or experts were involved in this item selection, "–" if target population or experts did not involve item selections, "0" if no information was found, and "?" if the

Table 2. Summary of neurodevelopmental assessment tools in each domain; screening, motor, language-cognition, and sensory-perception function

Assessment tool	Age range	Test type	Components tested	Diagnostic Criteria	Time to administer (min)	Availability of Korean version & education	Equipment/cost
Developmental delay screening							
DDST-II	0–6 yr	Criterion	Personal-social, fine motor-adaptive, language, gross motor	<Item interpretation> Caution: items that can be completed by 75%–90% of children but are failed Delay: items that can be completed by 90% of children but are failed <Overall interpretation> - Abnormal: in each area of development, more than 2 delays -Caution: 1 delay and/or 2 or more caution -Normal: no more than one caution	10–30	Korean ver.: available Education: none	Manual: ₩ 10,000 Total equipment: ₩ 130,000
K-DST	4–71 mo	Norm (3,010 children, Korea, 2010)	<18 mo: gross motor, fine motor, cognition, language, social skills ≥18 mo: same as above & self-help	Cutoff points at each domain, age -Recommendation for further evaluation: <-2 SD -Need for follow-up: -1 SD to -2 SD -Peer level: -1 SD to +1 SD -High level: >+1 SD	5–10	Korean ver.: available Education: National Health Insurance Corporation Online education	Free (provided by Korea Centers for Disease Control and Prevention)
K-ASQ	4–60 mo	Criterion	Communication, fine motor, gross motor, problem solving, personal-social	-Further assessment needed: at least one score below cutoff -Provide learning activities & monitor: at least one score adjacent to cutoff -Development is on track: all scores from each domain are above cutoff	10	Korean ver.: available Education: none	
Developmental delay diagnosis (discriminative)							
BSID-III[a]	1–42 mo	Norm (1,700 children from USA, 2000)	Gross motor, fine motor, cognitive, communication, social/emotional, adaptive	Developmental delay: <25-percentile or below 2 SD	30–90	Korean ver.: available Education: DVD, webinars, and workshops	1 set: ₩ 1,380,000
Motor function evaluation							
GMs	Preterm–5 mo	Criterion	Visual inspection of spontaneous movement	Preterm–6 wk: writhing movement -Normal -Abnormal (poor repertoire, cramped synchronized or chaotic) 9–20 wk: fidgety period -Present -Abnormal -Absent	5–20	Korean ver.: none Education: 4–5 day of authorized training course from GMs trust, providing certificates for each course (Basic, Advanced)	Free

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Table 2. Continued

Assessment tool	Age range	Test type	Components tested	Diagnostic Criteria	Time to administer (min)	Availability of Korean version & education	Equipment/cost
TIMP	34 wk (PMA)–4 mo (17 wk post-term)	Norm (990 infants, at risk of poor neurological outcome, USA, 2006)	Gross motor: 42 items of postural and selective control of movement - 13 Observed items for spontaneous movement: yes-no; 1–0 scores - 29 Elicited items in supported sitting, supine, prone, side lying, supported standing: 0–3, 0–4, 0–5, 0–6 scores	Raw score Percentile rank (<5%, 5%–15%, 15%–25%, 25%–50%, 50%–75%, 75%–95%, >95 percentile) Age standard: -Average -Below average: -1 SD to -2 SD -Far below average: <-2 SD	20–40	Korean ver.: none Manual: $38 Workshops, or e-Learning Course: thetimp.com	25 test forms: $68 Basic kit: $189 (including ball, cloth, rattle, etc.)
MAI	0–12 mo (m/c 4 mo)	Criterion	Gross motor, fine motor, muscle tone, primitive reflex, automatic reactions, volitional movements Total 65 items -Muscle tone: 1–6-points -Others: 1–4 points -High risk +1 points for each item	Cutoff of total scores (not validated) Developmental delay or abnormal : suspect 8–13 : high risk >13 : later neurological abnormality >10 : most probably normal <4	30–90	Korean ver.: none Manual: free Training recommended 2-day seminar; currently not available	Standardized equipment is necessary (including 2 chairs, bell, rattle, red ball, etc.)
AIMS	0–18 mo	Norm (2,200 infants, Canada, 1990–1992)	Gross motor (no. of items) Prone (21), supine (9), sitting (12), standing (16) : total 58 items Items observed as voluntary movements are identified among above 4 posture-specific items	Among all observed voluntary movements, the highest and lowest development stages are scored as window score Previous items created (below window score) are all checked as +1 Age-adjusted subscale score (sum) Developmental delay or abnormal: -At CA 4 mo: <10th percentile -At CA 8 mo: <5th percentile	20–25 Observation for each posture (without cue): ≥5 min recommended	Korean ver.: none Guideline book: $80	50sheets : $48.95
HINE[b)]	2–24 mo	Criterion	Scorable 5 domains: -Cranial nerve function -Posture -Movements -Muscle tone -Reflexes and protective reactions Non-scorable domains: -Motor milestones -Behavior	Each item 0–3 points Total score: 0–78 : optimal -At 3 mo: >67 -At 6 mo: >70 : risk of cerebral palsy -At 3 mo: ≤56 -At 12 mo: ≤65 <40: severe CP risk (non-ambulatory): -More predictive with general movement assessment together -Evaluation of right-left discrepancy is possible	10–15	Korean ver.: none Guideline book : $100 Workshops, teaching videos (online); currently not available anymore	Scoring sheets (on-line free) https://bpna.org.uk/userfiles/HINE%20proforma_07_07_17.pdf

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Table 2. Continued

Assessment tool	Age range	Test type	Components tested	Diagnostic Criteria	Time to administer (min)	Availability of Korean version & education	Equipment/cost
PDMS-II	0–6 yr (using CA until 2 yr)	Norm (2,003 infants, USA & Canada, 1997–1998)	A total of 6 subsets A. Gross motor -Reflex: 2 wk–11 mo -Stationary: body control -Locomotion: transfer (crawling, walking, running, hopping, jumping) -Object manipulation: 12 mo~ : catch, throw B. Fine motor -Grasping: hand function : hold, pincer grasp, buttoning/unbuttoning, etc. -Visual-motor integration: complex eye-hand coordination	Raw scores for each subtest Sum scores converted to standard score, %rank, age-equivalent Standard score sum TMQ (total motor quotient) -GMQ (gross motor quotient) -FMQ (fine motor quotient) <-1 SD : below average, caution <-2 SD: suspicious of developmental delay	45–60 (20–30 if only for motor-related subtest)	Korean ver.: available (for research-use only) Manual: $100	Kit: ~$550 Test kit provides most of all equipment Online scoring & report system: available
NSMDA	1 mo–6 yr	Criterion	6 Subscales (gross motor, fine motor, neurological, primitive reflexes, postural reactions, motor response to sensory input); abnormal, suspicious, normal	Functional score 6–8: normal motor function 9–11: minimal motor problem 12–14: mild motor problem 15–19 moderate motor problem 20–25 severe motor problem >25 profound disability	20–45	Korean ver.: none Comprehensive manual: £35	Specific toys required but easily accessible
Language function evaluation (Korean)							
SELSI	4–35 mo	Norm	56 Questions for receptive and expressive language, respectively	Raw scores, equivalent age, percentile for semantics, phonology, syntax, and pragmatics <-1 SD: caution <-2 SD: advised for further evaluation about language delay			₩ 123,300 (including all equipment and manual)
PRES	2–6 yr (preschool)	Norm	45 Questions for receptive and expressive language, respectively	Raw scores, equivalent age, percentile for semantics, phonology/syntax, and pragmatics			₩ 300,000 (including all equipment and manual)
P-FA	Preschool, elementary & middle school	Norm	Fluency: word picture, repetition, sentence picture, reading, story picture, speaking picture (according to age level) Communication skills (not in preschool evaluation): any burden/difficulty in speaking or stuttering	Raw scores, score distribution and percentile			₩ 361,000 (including all equipment and manual)

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Table 2. Continued

Assessment tool	Age range	Test type	Components tested	Diagnostic Criteria	Time to administer (min)	Availability of Korean version & education	Equipment/cost
K-M-B CDI	8–17 mo (infant) 18–30 mo (toddler)	Norm	Parent-report form to evaluate communication skills	Level I (infant): words and gestures; short form – 89-word vocabulary checklist Level IIA/B (toddler): words and sentences; 100-word productive vocabulary checklist, questions about combining words			₩ 90,000 (including all equipment and manual)
PPVT-R	2 yr–8 yr 11 mo	Norm	Language comprehension, receptive vocabulary skills : Total 178 vocabulary	The first question is determined by age, If 8 correct answers consecutively, this point is set as the baseline. (all questions before the point are scored as correct) If 6 out of 8 consecutive questions are incorrect, the last incorrect questions is the upper limit; Raw score with only correct answers to be calculated as percentile, equivalent age			₩ 1,400,000 (including all equipment and manual)
REVT	2 yr 6 mo –16 yr	Norm	Receptive/expressive vocabulary skills (initially developed for Korean vocabulary) : 185 Questions (using pictures) for receptive and expressive domain, respectively	Scoring is same with PPVT-R <-1 SD: below average, caution <-2 SD: advised for further evaluation for vocabulary development			₩ 380,000 (including all equipment and manual)
PCAT	2–12 yr or preschool	Criterion (% accuracy)	Ability to modulate consonant pronunciation (using pictures) : 30 Words including 43 phonemes	For speech therapy for articulation, : consider <-1 SD, demand <-2 SD			
Cognitive function evaluation							
K-WPPSI-IV	2 yr 6 mo–3 yr 11 mo & 4 yr–7 yr 7 mo	Norm	FSIQ Primary index scale (comprehensive cognitive functioning): composite scores of verbal comprehension index, visual spatial index, working memory index and fluid reasoning index, processing speed index for older age band Ancillary index scale: verbal acquisition index, nonverbal index, general ability index and cognitive proficiency index for older age band	Raw scores from the subset Age-corrected standard scores of scaled and composite scores (percentile) for FSIQ and each subset scores	30–60		
Sensory-perception function evaluation							
VMI-6	2–90 yr	Norm (1,882 Korean, 2–90 yr)	Visual-motor integration, visual perception, motor coordination (spontaneous scribbling task, imitated scribbling task, imitation task)	Raw scores: success until 3 consecutive fails Equivalent age, standard score, percentile for screening visual motor coordination function	10–15	Korean ver.: available Education: none	With manual : ₩ 110,000 Without manual : ₩ 90,000

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Table 2. Continued

Assessment tool	Age range	Test type	Components tested	Diagnostic Criteria	Time to administer (min)	Availability of Korean version & education	Equipment/cost
Neonatal Visual Assessment	GA 35 wk–1 yr	Norm (110 healthy full-term neonate at 72 h, Italy)	9 Items of spontaneous ocular motility, ocular movements with target, fixation, tracking (horizontal, vertical, arc), reaction to a colored contrast target, ability to discriminate stripes, attention at distance	Each item scored 0 if <90 percentile, scored 1 if abnormal Global score ≥2: abnormal	5–10	Korean ver.: none Education: none	Free
PreViAs	CA 0–24 mo	Norm (298 children from Spain)	Questionnaires of 30 items, 4 domains : visual attention; visual communication; visual-motor coordination; visual processing	Mean scores of each domain Cutoff points for each visual domain and each age group by 2 mo		Korean ver.: none Education: none	Free
SP1	Infant SP1 0–6 mo Toddler SP1 7–36 mo SP1 3–10 yr Adolescent/adult SP1 ≥11 yr	Norm (1,037 children without disability, 32 children with autism and 61 with ADHD from USA)	Sensory processing (auditory, visual, vestibular, touch, multisensory, oral sensory), Modulation (sensory processing related to endurance/tone, body position/movement, movement affection activity level, sensory input affecting emotional responses, visual input affecting emotional responses and activity), Behavioral and emotional responses (emotional/social responses, behavioral outcomes of sensory processing, items indicating thresholds for responses)	Sensory seeking, emotionally reactive, low endurance/tone, oral sensory sensitivity, inattention/distractibility, poor registration, sensory sensitivity, sedentary, fine motor/perceptual Typical performance <-1 SD: possible difference <-2 SD: definite difference	20–30	Korean ver.: available Comprehensive manual : included in questionnaire	Questionnaire: $193 No special equipment
SP2	Infant SP2 0–6 mo Toddler SP2 7–35 mo Child SP2 3–14 yr 11 mo Short SP2 3–14 yr 11 mo School companion SP2 3–14 yr 11 mo	Norm (1,791 from USA)	Sensory sections: auditory, visual, touch, movement, body position, oral Behavioral sections: conduct, social emotional, attentional Caregiver questionnaire for 5 Likert score (1–5)	Seeking score: degree to which a child obtains sensory input Avoiding score: degree to which a child is bothered by sensory input Sensitivity: degree to which a child detects sensory input (notification of sensory input) Registration: degree to which a child missss sensory input Raw scores, percentile range, standardized scores -1 SD to +1 SD: normal <-1 SD: less than others <-2 SD: much less than others >+1 SD: more than others >+2 SD: much more than others	5–20	Korean ver.: none Comprehensive manual : included in questionnaire	Questionnaire: $292 No special equipment
SPM-P	2–5 yr	Norm (651 typically developing children from USA)	Social participation, vision, hearing, touch, total sensory system/taste and smell, body awareness, balance and motion, planning and ideas	Typical range (T-score: 40–59) Some problems range (T-score: 60–69) Definite dysfunction range (T-score: 70–80)	15–20	Korean ver.: none Education: none	Paper and online kit $160

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Table 2. Continued

Assessment tool	Age range	Test type	Components tested	Diagnostic Criteria	Time to administer (min)	Availability of Korean version & education	Equipment/cost
TSFI	4-18 mo	Norm (196 infants as typically developing, 27 infants with delayed, 27 difficult temperament infants, USA)	24 Items of 5 domains: tactile deep pressure, visual tactile integration, vestibular functions, ocular motor control, reactivity to vestibular stimulation	Item scoring for each domain, Total test score: overall score of sensory processing and reactivity, Cut-off points to diagnose sensory integrative dysfunction	20	Korean ver.: none Comprehensive manual: included in test kit	Test kit (US $199) Test kit provides most equipment

DDST-II, Denver Development Screening Test-II; K-DST, Korean-Developmental Screening Test; SD, standard deviation; K-ASQ, Korean-Ages and Stages Questionnaires; BSID-III, Bayley Scales of Infant Development-III ([a]version IV is also available in English from 2019; same five domains but scoring is changed from dichotomous to polytomous(2,1,0) with decreased number of items to make 30% less time needed to complete the assessment); GMs, general movements; TIMP, Test of Infant Motor Performance; PMA, postmenstrual age; MAI, Movement Assessment of Infants; AIMS, Alberta Infant Motor Scale; CA, corrected age; HINE, Hammersmith Infant Neurologic Examination ([b]HNNE, Hammersmith Neonatal Neurological Examination also available); CP, cerebral palsy; PDMS-II, Peabody Developmental Motor Scales-II; NSMDA, Neuro-sensory Motor Developmental Assessment; SELSI, Sequenced Language Scale for Infants; PRES, Preschool Receptive-Expressive Language Scale; P-FA, Paradise-Fluency Assessment; K-M-B CDI, Korean-MacArthur-Bates Communicative Development Inventories; PPVT-R, Peabody Picture Vocabulary Test-Revised; REVT, Receptive Expressive Vocabulary Test; PCAT, picture consonant articulation test; K-WPPSI-IV, Korean-Wechsler Preschool and Primary Scale of Intelligence-IV (version V is also available from 2019); FSIQ, full scale intelligence quotient; VMI-6, Developmental Test of Visual-Motor Integration-6; GA, gestational age; PreViAs, Preverbal Visual Assessment; SP1, Sensory Profile 1; SP2, Sensory Profile 2; SPM-P, Sensory Processing Measure-Preschool; TSFI, Test of Sensory Functions in Infants.

description of these aspects is lacking. Criterion validity is the extent to which the test scores are related to a gold standard, and is demonstrated through the correlation coefficient: "+" if coefficient ≥0.70, "–" if <0.70, and "0" if no information is suggested. Construct validity is the extent to which scores on a specific domain measure the intended theoretical construct or concept. It is assessed as "+" if specific hypotheses were formulated and ≥75% of the results are in accordance, "–" if <75% of hypotheses were confirmed, "0" if no information was available, and "?" only if doubtful hypotheses or method exists [16].

Developmental delay screening

Screening tools are often used prior to an accurate diagnosis of developmental delay. A literature search for proper developmental delay screening tools, revealed that K-DST [17], and Korean-Ages and Stages Questionnaires (K-ASQ) [18,19] are available in Korean versions. The first screening is usually performed with DDST-II, inclusive of the gross motor, fine motor-adaptive, language, and personal-social domains [20]. "Delay" is indicated if a child fails an item that more than 90% of children of the same chronological age were able to do, and "caution" is indicated if a child fails an item that 75%–90% of children of the same chronological age were able to do. Developmental delay was suspected if there were two or more cautions and/or one or more delays. This criterion-based test showed a high inter-observer and test-retest reliability and sensitivity of 0.83 and specificity of 0.51, respectively [21,22]. If a developmental disorder is suspected from DDST-II, a more thorough, discriminative evaluation of BSID is usually recommended to follow as a diagnostic assessment, which is norm-based test to evaluate gross motor, fine motor, cognition, communication, social/emotional, and adaptive domains, which can suggest a high risk of developmental delay if below 2 standard deviation (<25 percentile) [23,24]. BSID is popularly used to diagnose developmental delay in terms of which domain shows a problem and how much delay is presented in terms of percentiles [18,25]. In particular, BSID at the age of 2 years is known to predict motor impairment at the age of 4 years old [10,26].

Motor function

Standardized neuromotor assessment tools are intended to discriminate or identify any abnormalities in antigravity and/or spontaneous movements elicited by infant motor patterns, reflexes, or muscle tone [27]. In contrast, most neurobehavioral assessment tools assume that the emergence of motor skills follows the same sequence as rolling, sitting, crawling, and walking and evaluate social/attentional and autonomic responses of infants according to gestational age. Although the Hammersmith Infant Neurologic Examination (HINE) evaluates both neurological and neurobehavioral domains, only a neurological domain of cranial nerve function, posture, voluntary movement, tone, and reflexes/reactions are scored to describe the risk of cerebral palsy (CP). Also, the Movement Assessment of Infants (MAI), PDMS for infant (from 2 weeks to 11 months CA), and Neurosensory Motor Developmental Assessment (NSMDA) evaluate both domains; scoring primitive reflexes, postural reactions, and muscle tone for neuromotor assessment as well as checking gross and fine motor development through observing elicited or volitional movements for neurobehavioral assessment.

The general movements (GMs), HINE, and Test of Infant Motor Performance (TIMP) are the most popular neurodevelopmental assessment tools that are recommended for the early diagnosis of CP before 5 months' CA, together with brain imaging evaluations [14]. As well as considering risk factors (Table 1), early detection of CP or other developmental disorders can be achieved with using a combination of several standardized motor assessment tools and proper neuroimaging [14]. In infants with later infancy after 5 months' CA, additional to HINE, the physical development domain of Developmental Assessment of Young Children, Alberta Infant Motor Scale (AIMS), and NSMDA are also recommended in combination as known to be predictive in the diagnosis of motor impairments, especially when brain magnetic resonance imaging is neither affordable nor available due to safety conditions [14,28].

During the earliest age, GM is useful and "fidgety" movement during CA between 3 and 4 months of age has been shown to have the best predictive validity of motor impairments [29,30]. Both GM and TIMP showed the strongest psychometric properties and predictive validity to better anticipate future motor outcomes and evaluate the effect of interventions [27]. On the other hand, HINE focuses more on neurologic impairment than on current motor function to propose a cutoff score in each age range to discriminate the risks of permanent motor impairment [31,32]. PDMS and AIMS have strong discriminative validity because they have a norm-referenced value from sufficiently large populations [33,34]. MAI is strong at an earlier age (younger than 4 months), such as GM and TIMP, while AIMS and NSMDA are generally for older ages (8–12-month-old) [35].

Various assessment tools exist specifically for each age band and subtest domain for NICU graduates to detect subtle changes in motor development for stratification of the severity of motor impairments and evaluation of the effect of treatment. Therefore, a uniform use of comprehensive motor assessment tools for sequential follow-up with a large population would be helpful in clarifying how NICU graduates follow and catch up on motor development milestones. Unfortunately, only PDMS is available in the formerly Korean-translated version; however, most other tools are already in common use with the English version. Although motor development is assumed to be similar in different countries, the new population displays different norms for each assessment tool [36]. Professionals involved in motor surveillance should also remember cultural effects on motor milestones and context-specific test results.

Language and cognitive function

If the language scale from the BSID results is suggestive of language function impairments, standardized language assessment batteries usually follow. New language assessment tools using the Korean language should be developed to evaluate communication skills. For comprehensive language evaluation, the Preschool Receptive-Expressive Language Scale (PRES) and the Sequenced Language Scale for Infants (SELSI) are the most popular and widely used tools with 56 questions on SELSI and 45 questions in PRES for receptive and expressive language, respectively [37]. The Paradise-Fluency Assessment (P-FA) assesses fluency using a picture representing words, sentences or speaking, and repetition task [38]; and Korean-MacArthur-Bates Communicative Development Inventories (K-M-B CDI) utilizes parent-report questionnaires about a vocabulary checklist to evaluate communication skills [39]. The Peabody Picture Vocabulary Test-Revised (PPVT-R) and the Receptive Expressive Vocabulary Test (REVT) are tools for assessing vocabulary capacity. Although different target age ranges are suggested for each assessment tool, a combination of several tools is usually recommended owing to the different test domains and scoring methods (Table 2) [37].

These language assessment tools use structured question orders, since more difficult questions for older children appear later than easier questions. Therefore, a norm-based interpretation can be used based on score distributions according to each age band, usually at 2–3-month intervals, with mean values and standard deviations. Then, the result can report the raw scores of each domain, which can be calculated as equivalent age and percentile. Picture consonant articulation test (PCAT) is only a criterion-based test that calculates percentage of correctly pronounced consonants (% accuracy). It uses an object containing the phoneme to be tested or a corresponding picture, and asks children to speak the word to evaluate the accuracy of articulation and to determine any disability or articulation based on the age at which certain consonants are acquired [40].

In Table 2, the time to administer and the availability of Korean versions/education are empty for language assessment tools. The time taken for language assessments varies considerably according to individual cooperation or cognitive level, medical status, and environment. It is difficult to accurately estimate the time required; however, 30–60 minutes are usually allocated as the evaluation time. Education for language assessment is unavailable to common users because speech and language pathologists with professional training, degrees, and national certification oversee every language assessment and treatment in Korea. Therefore, essential personnel preparation must first be established for follow-up language assessments.

As an initial screening tool for cognition, the cognitive scale from the BSID is useful for the age range of up to 42 months. The Wechsler Preschool and Primary Scale of Intelligence (WPPSI) is the most popular assessment tool for evaluating cognition. The Wechsler Intelligence Scale for Children (WISC) is for higher age, although some overlapping age bands exist around 6 to 7 years [41]. When interpreting the different results of each evaluation tool around this age, clinicians should remember that the two tests can produce a different cognitive profile, and WISC could result in lower scores on the subtest of vocabulary, matrix reasoning, and bug/symbol search compared to WPPSI [41].

Sensory-perception function

Sensory perception is important in early development, especially during critical periods of neuroplasticity and refinement [42]. Because most early interventions focus on an enriching environment for this neuroplasticity, the existence of sensory deprivation is a huge barrier for NICU graduates to catch up on developmental milestones after discharge. Most NICU graduates suffer from visual perception, visual-motor integration, and coordination impairments that affect later learning disabilities and school activities [43]. Therefore, appropriate sensory perception function assessments must be combined with regular developmental follow-up programs.

For visual sense assessment tools, the neonatal visual assessment is for the earliest age from 35 weeks to 1 year of age, which is appropriate for use during NICU stay [44]. Preverbal Visual Assessment (PreViAs), a simple questionnaire of 30 items, is for 0–24 months old babies [44,45], while the VMI-6, a nonverbal test using figure and shapes, culture-free, standardized easy tool, is for 2–90 years old including adults, which can provide a result of equivalent age for visual motor coordination function [46]. The Sensory Processing Measure-Preschool (SPM-P) is for preschool age of 2–5 years old and assesses how the child is processing sensory stimuli and how the sensory needs are reacting to different environments. The social participation measure is unique in the SPM-P and can evaluate over/under-responsiveness to sensory stimuli [47]. Sensory Profile 2 is a recently updated version of Sensory Profile 1 for infant (0–6 months), toddler (7–35 months), and child (3–14 years old). This tool requests for caregiver observations or judgment about sensory processing patterns and impact on functional performance, giving the score for each quadrant of searching, avoiding, sensitivity, and registration [48,49]. The Test of Sensory Functions in Infants (TSFI) tests five domains: tactile deep pressure, visual tactile integration, vestibular functions, ocular motor control, and reactivity to vestibular stimulation [50,51]. A stronger understanding of how children's sensory processing patterns can impact daily function, participation, and daily activities is needed to plan further interventions.

CONCLUSION

This guideline summarizes neurodevelopmental surveillance methods for patients who have been cared for and discharged from the NICU until the age of approximately 3 years. This is based on risk factor stratification and currently available assessment tools for each development domain. This surveillance program aims to enable early diagnosis and timely intervention for people with developmental disorders to support their functions and quality of life. Although there is still a lack of evidence-based early treatment guidelines for NICU graduates, this standardized post-discharge neuromotor development surveillance program would lead to a more concrete database for identifying those who need early rehabilitation interventions in the future.

CONFLICTS OF INTEREST

Jeong-Yi Kwon, Bo Young Hong, and Jin A Yoon are the editorial board members of Annals of Rehabilitation Medicine. The authors did not engage in any part of the review and decision-making process for this manuscript. Otherwise, no potential conflict

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AUTHOR CONTRIBUTION

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SUPPLEMENTARY MATERIALS

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