## Starting Strong: Dietary, Behavioral, and Environmental Factors that Promote “Strength” from Conception to Age 2 Years

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Starting Strong: Dietary, Behavioral, and Environmental Factors that Promote “Strength”

from Conception to Age 2 Years

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Short Running Head: Starting Strong

Sources of Support: The Beef Checkoff.

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Abstract

Beginning with conception and continuing through childhood and adolescence, the word “strength” connotes the totality of optimal early bone and tissue growth, neural wiring of the brain, and acquisition of fine motor, gross motor, language, and social-emotional skills. The robustness of each of these attributes depend on three critical epigenetic (external) factors: the quality of nutrition; positive adult nurturing; and experiences acquired within a stimulating, safe environment that affords free exploration. This review highlights the relationship between the epigenetic factors in the period of conception to age 2 years and a child’s future health, cognitive capacity, and social aptitude, which collectively comprise their “strength”. This paper was presented as part of the 2018 Strength Summit conference entitled, The Role of Strength in Optimal Health and Well-being.

Keywords: strength, B-24 months, children, nutrition, epigenetics, pediatrics, health

Novelty Points:

- Strength in infants signifies the totality of optimal early growth and neural wiring of the brain.
- Strength at this life stage also includes the acquisition of motor, language, and social-emotional skills.
- Three epigenetic factors are critical during birth to 24-months: nutrition, nurturing, and free exploration.
Introduction

When applied to a child, the concept of strength encompasses not only the quality of bone and muscle mass, but also that of brain expansion, acquisition of fine and gross motor abilities, communication techniques, cognitive processing, and social and emotional skills. Although genes will heavily influence the growth of the child throughout late childhood and early adolescence, it is a child’s epigenetic (environmental) exposures that promote or hinder strength acquisition during the early years (Millward 2017; Shankar et al. 2018). The quality of three epigenetic factors are critical: nutrition, nurturing, and environment for free exploration.

Both parents contribute to the trajectory of their child’s development during the period of periconception. Egg and sperm cell lines reflect accumulated risk factors associated with stress, environmental toxins, excessive alcohol consumption, smoking, lack of exercise, obesity, ill-health, and the use of illicit drugs (Soubry 2018). The mother’s physical and mental status throughout pregnancy will determine the in-utero environment of the growing fetus (Shankar et al. 2018; Kwon and Kim 2017; Choi and Friso 2010). Contributors to adverse maternal well-being will alter fetal development, resulting in a high risk for later chronic diseases, including cardiovascular diseases, metabolic diseases, cancers, obesity and even behavioral disorders (Larque et al. 2019; Khambadkone et al. 2020). Epigenetic factors remain predominant stimuli for optimal growth and development in the months and years following birth (Shankar et al. 2018).
Epigenetic influences affecting fetal and neonatal strength

In early life, the concept of strength must encompass not only physical stature, but also the extent to which development affects the potential for adversity and disease. Health risks can arise during development as a result of environmental factors that manipulate the function of the child’s genes (Brenseke et al. 2013). Human genes are strands of DNA code that direct the production of proteins within cells. Such proteins serve as building blocks for all the cells, tissues, organs, as well as determinants of their functional capacity (Kwon and Kim 2017). But it is environmental (epigenetic) exposures that direct how, when, and the extent to which the DNA code is expressed as proteins within cells (Choi and Friso 2010).

Research suggests that even paternal and maternal preconception health will directly and indirectly impact conception, the pregnancy, and the subsequent life-long health of the newborn (Kotelchuck and Lu 2017; Cirulli et al 2020). Epigenetic factors surrounding the pregnant woman continue to be extremely important throughout pregnancy, impacting the pregnancy’s outcome, the mother’s health, and the newborn’s development (Shankar et al 2018; Larque et al. 2019; Cirulli et al. 2020). Maternal over-consumption or under-consumption of energy, or specific micronutrient imbalances in her diet, have the potential to alter the developmental trajectory of every cell, tissue, and organ in the emerging fetal body, depending on extent and timing during the 9 months of pregnancy. Similarly, maternal exposure to toxins, drugs, infections, or poorly managed chronic illnesses, can create an adverse uterine environment surrounding the growing fetus, which can permanently alter growth velocity and produce anomalous tissue function (Kwon and Kim 2017; Larque et al. 2019; Brenseke et al. 2013). Abnormal birth weight for gestational age (both low and high) will directly influence
muscle mass and strength and can affect a child's ultimate adult height (stunted versus normal) and body composition (lean mass versus fat mass) (Dodds et al. 2012; Barr et al. 2010).

Unlike birth weight, not all the consequences of adverse fetal uterine exposures are immediately measurable at birth. A risk for future cardio-metabolic diseases, including cardiovascular diseases (hypertension, heart disease, stroke), metabolic diseases (obesity, diabetes), cancers, and even mental health conditions (anxiety, depression, bipolar disease), can be “programmed” during fetal development, yet only manifest later in life, as described by the Developmental Origins of Adult Health and Disease hypothesis (DOHaD) (Kwon and Kim 2017; Brenseke et al. 2013).

To counter risk, the assessment of the pregnant woman begins with a health screening, including existing clinical conditions, such as hypertension and diabetes, anemia, asthma, depression, and autoimmune diseases, and the extent of their control. Red flags are noted that may threaten the outcome of the pregnancy, such as tobacco, drugs, or alcohol use, poor maternal dietary habits, physical inactivity, and preconception over- or under-weight (Kwon and Kim 2013; Khambadkone et al. 2020; Rasmussen and Yaktine 2009). By measuring and monitoring the mother's health, lifestyle habits, and weight gain, and by measuring fetal growth relative to post-conception dates, using physical examination and ultrasound, the clinician can minimize potential problems for the fetus. Recent research has begun to examine ways to mitigate health risks postnatally, as well, utilizing parental guidance, diet quality, regular physical activity, and weight management (Shankar et al. 2018; CDC 2020; Boone-Heinonen et al. 2015)
Epigenetic influences of nutrition that affect strength in infants and toddlers

The three primary environmental exposures – nutrition, nurturing, and environment – are central to building strength after birth. In a landmark study, the World Health Organization closely monitored the growth velocity of a representative cohort of newborn infants from 6 different countries around the world (World Health Organization 2006) Growth was followed from birth to age 5 years. To eliminate confounders that might hinder optimal well-being, enrolled neonates were from financially secure, non-smoking families and were exclusively breastfed during their initial 6 months of life. The infants showed almost identical growth velocity between birth and 5 years irrespective of their country of origin or ethnic background.

The finding that healthy, well-nourished infants grow at similar velocities suggested that children who display slower growth relative to this growth standard are environmentally small, not genetically preordained as small. Along with family socioeconomic status, poor hygiene, and unsanitary conditions, less recognized contributing factors entail conditions surrounding the mother, including adolescent pregnancy, low education, poor health, physical labor, and chronic low-quality food (Danaei et al. 2016). The highest risk for growth failure is at the time of weaning, with the introduction of foods and beverages other than breastmilk or infant formula (Murray 2018).

Conversely, an infant who grows above the WHO growth standard during the first months of life should be considered environmentally large, that is, affected by excess energy or inappropriate parenting practices that will predispose an infant to excess adiposity later in life (Shankar et al. 2018; Larque et al. 2019). Infants exposed to solid foods and beverages before 4 months of age, those habitually offered high-energy low-nutrient items early in life, such as
desserts or sugar-sweetened beverages, or those served diets that include protein levels in excess of 10-15% percent of total daily energy, appear to be at a higher risk for obesity with age (Larque et al. 2019) For these reasons, monitoring height, weight, and age-adjusted weight-for-height (or BMI) z-scores is a fundamental practice for pediatric and public health professionals (Murray 2018).

Breastfeeding is considered fundamental for many reasons. The World Health Organization (WHO) estimates that if exclusive breastfeeding were universal for 6 months it would lower infant deaths by 820,000 world-wide (Arts et al. 2018). Breastmilk is more than just optimal nutrition. It also provides bioactive factors that protect the vulnerable neonate from pathogens, stimulate continued organ development, initiate rapid immune development, and trigger the establishment of a beneficial colonic microbial community (Andreas et al. 2015).

During the birth process the neonate comes in contact with billions of bacteria, many of them pathogenic, via the skin, nasal-respiratory passages, and oral cavity. To keep from being overwhelmed, the neonate consumes active immunologic protective factors in breastmilk, to augment maternal immunoglobulins that were passed trans-placentally. The neonate’s innate immune cells lining the GI and respiratory tracts and the development of a relatively hostile gastric and intestinal environment serve to retard pathogen growth. Breast milk immunoglobulins, lactoferrin, complement, leukocytes, and anti-viral mucins, along with cytokines and other anti-inflammatory molecules help protect the neonate as the evolving elements of the immune system adjust to novel environmental stimuli (Andreas et al. 2015).

Recent research has examined the functions of human milk oligosaccharides (HMOs), the second most abundant macronutrient fraction in breast milk (at approximately 12 g/L)
(Bode 2015; Lonnerdal 2016). These carbohydrates are indigestible, providing no nutritional value. Discovered nearly 100 years ago, their exact functions remained unclear until novel research technologies provided the tools to study them. HMOs are a critical support for the transition from in-utero to ex-utero life helping to limit pathogen adhesion. By flooding the intestine with prebiotic carbohydrates, HMOs encourage a dense, beneficial colonic microflora, dropping the luminal pH, and discouraging the growth of pathogens. A stable microflora tends to persist over the life course (Davis et al. 2017) Studies have shown that bacterial metabolic byproducts communicate with human systems to help maintain metabolic homeostasis in spite of wide fluctuations in clinical conditions over time, making the intestinal microbial community a component of a child’s strength (Tan et al. 2014; Canfora et al. 2015; Greenblum et al. 2012).

In the well-nourished child, birth weight will triple in just the first 12 months and birth length will double by age 5 years (Arts et al. 2018). Additionally, synaptogenesis and axon myelination will double brain volume in just 12 months and triple it by 36 months, reaching 85% of final adult size (Larque et al. 2019). This extraordinary growth velocity is reflected by a basal metabolic rate that is more than 2.5 times that of an adult, of which 50% is accounted for by brain activity alone (Son”kin and Tamboytseva 2012). For these reasons, the infant’s needs for additional energy and iron for growth necessitates the introduction of complementary solid foods to augment breastmilk after age 6 months (Murray 2017).

Between 6 months and 24 months, infants will experience their first solid foods, flavors, and textures. They steadily expand their food experiences, and eventually adopt a more stable dietary pattern after age 2 years (Shankar et al. 2018; Murray 2017; Roess at al. 2016; Birch and Doub 2014). The period of complementary feeding can be divided into two phases: phase one,
the introduction of first foods from 6-12 months. The goals for phase one include introducing a wide array of foods from each food group on a rotating basis to ensure the infant’s acceptance. In addition, during this time, the infant will become adept dealing with increasingly coarser food textures. Phase two represents an expansion of food tastes and combinations from each of the 5 food groups that will, collectively, shape the child’s personal dietary pattern by 24 months.

Complete, balanced nutrition is critical during the complementary feeding period, not only to match the high energy needs to achieve bone and tissue growth, but also to provide the consistent nutrient pool required for the rapid growth of different regions of the brain. Although individual nutrients such as omega-3 fatty acids, iron, choline, lutein, and vitamin D are widely researched and discussed, it takes many nutrients to build, maintain, and preserve body and brain function (Holland et al. 2014; Gonzalez and Visentin 2016; Georgieff et al 2018).

Nutrient requirements during this critical stage necessitates feeding several times per day, affording adults many opportunities to nurture their toddler’s developing food preferences. A responsive parenting style — that is, a reciprocal responsiveness between the child and the caregiver — is optimal to guide food acceptance and establish a highly nutritious dietary pattern (Shankar et al. 2018; Murray 2017; Perez-Escamilla et al. 2017).

**Epigenetic influences of nurturing that affect strength in infants and toddlers**

Positive and supportive adult responsiveness is the most influential positive factor in child development during the critical early years (Center on the Developing Child 2020; Shonkoff and Garner 2012). Adults who engage the young child in back-and-forth
communication, so-called “serve-and-return”, establish a sense of security and encouragement (Center on the Developing Child 2020). Whether its baby talk, touching, singing, speaking, physical play, reading, or simple shared day-to-day experiences, such as eating together or family routines, this reciprocal, face-to-face exchange is the basis of social and emotional learning, something that will serve not only to foster neuro-cognitive development, but also to buffer the child from potentially damaging adverse life events.

Recent research methodologies have provided a fresh perspective on how external events alter how children develop. One of the most important findings has been the complex role of recurring stress (Felitti et al. 1998; Gilbert et al. 2010; Yossef et al. 2017). Children, like all humans, face stresses every day. Most come in the form of simple challenges or frustrations, such as learning to walk or master language. For a young child engaged in exploration, these kinds of routine stresses are the basis for learning. They build confidence, cognition, and personality traits and thus are positive (Center on the Developing Child 2020). But not all stresses are so simple. More severe challenges, termed “adverse childhood events” (ACEs), have the potential to overwhelm a child or adolescent emotionally (Shonkoff and Garner 2012; Gelitti et al. 1998). Experiencing violence, abuse, or other forms of trauma, such as neglect, family chaos, chronic illness, or divorce, have the capacity to inflict permanent impairment to the development of crucial mental processes (impulse and emotional control, flexible thinking, persistence, self-monitoring, planning and priorities, organization). Acquisition of these higher-order “executive skills” are imperative for academic and social success (Center on the Developing Child 2020; Shonkoff and Garner 2012).
ACEs are epigenetic. That is, they are external events that can substantially alter an individual’s gene function, releasing a surge of fight-or-flight hormones, (cortisol, adrenaline, noradrenaline) (Shonkoff and Garner 2012). Once relieved of the stress, the body adjusts and reestablishes its baseline homeostasis. But when ACEs are severe, prolonged, or recurrent, homeostasis cannot be achieved. The abnormal physiology and psychology of stress itself becomes a new baseline and, with time, a permanent one (Shonkoff and Garner 2012). ACEs are remarkably common. Two-thirds of adults surveyed across 23 states reported that they had experienced at least one ACE during childhood and nearly one-quarter reported that they had experienced three or more ACEs (Merrick et al. 2018). The higher the accumulated ACEs, the more extensive the damage (Feliiti et al. 1998; Gilbert et al. 2015; Youssef et al. 2017; Merrick et al. 2018).

When ACEs are measured, individuals with higher cumulative scores tend to show a characteristic pattern to their subsequent life course (Shonkoff and Garner 2012; Feliiti et al. 1998; Gilbert et al. 2015; Youssef et al. 2017; Merrick et al. 2018). In early years, neurodevelopment is disrupted, rewiring their neural pathways in ways that hamper their acquisition of cognitive, executive, and social skills. During school age, this manifests as impulsiveness, anxiety, inattention, aggression and agitation. Weak social and emotional abilities impair their social connections. Academic achievement suffers. Immature executive skills lead to more high-risk behaviors during adolescence and young adulthood. Adult productivity falls far below what the individual might have otherwise achieved, often accompanied by health and mental health issues and early death. These are preventable outcomes (Centers for Disease Control and Prevention 2019).
And yet, not all children or adolescents with a history of severe ACEs show the characteristic damage. The difference between ACEs being tolerable (the child overcomes) or toxic (the child is overwhelmed) depends on the child’s response, not on the stress itself (Shonkoff and Garner 2012; Centers for Disease Control and Prevention 2019). Research suggests that the key attribute of a resilient child is their ability to draw on strengths and skills that have been nurtured by caring adults during the formative years. That is, at least one supportive, encouraging adult has provided sufficient emotional shelter for the child to practice and master executive processes and social-emotional skills sufficient to buffer them against seemingly overwhelming adversity. At any age, this represents a powerful example of strength.

**Epigenetic influences of the environment that affect strength in infants and toddlers**

The transformation from simple neonatal reflexes into complex skills in early childhood represents one of the most striking examples of the influence of post-natal epigenetic factors on strength. The neonate is born with a toolbox of rudimentary reflexes — suck-and-swallow, grasp, stepping, rooting, and so forth (Hagan et al. 2017). Parturition results in a sudden sensory explosion for the neonate -- sights, sounds, smells, tastes, and skin contact – as well as the weight of gravity and free movement of limbs. Immediately at birth, the infant begins a profound sensory and motor exploration, stimulating an estimated 700 new synapses established per second during the first months of life (Center on the Developing Child 2020). Starting from a few rudimentary reflexes, nascent sensory-motor exploratory skills evolve, becoming increasing complex and habitual. Synaptogenesis and myelination, the laying down of fatty insulation of axons to increase the speed of impulse conduction, drive extraordinary
brain growth between birth and 36 months (Hagan et al. 2017). It is sensory-motor environmental exploration that lays the foundation for fine motor, gross motor, communication, and social competence, and is the platform for the infant’s future cognitive capacity (Center on the Developing Child 2020). Ensuring the provision of the supportive “scaffolding” for skill development, which are provided through quality nutrition, nurturing, and environment, makes the foundation strong (Hagan et al. 2017; Schwarzenberg and Georgieff 2018).

As the neonate acquires the attributes of the infant, toddler, child, and adolescent, the environment around them continuously expands in scope, along with their ability to engage it. Commonly, the word “play” is used to describe a child’s earliest interaction with their environment. But play is not frivolous. It is an intense form of exploration and socialization and as such, extremely serious (Yogman et al. 2018; Mendelsohn et al. 2018). At every stage, children seek out novelty and through it ways to extend their influence. Creating a stimulating, age-appropriate, safe environment for play provides an effective path to enhance a child's strength. Neglect, a profound lack of social and cognitive stimulation, is among the most damaging forms of abuse in pediatrics (Shonkoff and Garner 2012; Center on the Developing Child 2020).

Play promotes child strength in four valuable ways: physical activity (physical strength, motor skills, stress relief), peer interactions (social and emotional skill-building), practice of executive functions (emotional control, planning, persistence, teamwork), and stress relief (joy, self-expression, creativity) (Yogman et al. 2018; Murray and Ramstetter 2013).
At its most basic, play can be divided into free play (child-directed) versus structured play (adult- or rule-directed). These can take many forms, including play that is pretend or creative, rough-and-tumble, outdoor, sports and games, puzzles, and object manipulation (throwing, kicking, batting, etc.) (Yogman et al. 2018; Murray and Ramstetter 2013). Types of play and the environments in which children play vary depending on the child’s developmental stage. Along with mastery of physical challenges, play teaches and refines cortical executive functions and emotional control. Puzzles, for example, require patience, persistence, and experimentation through trial-and-error. Whether in the home, in child-care centers, on playgrounds, in preschools and schools, or broadly across the community, adults have a responsibility to provide the types of environments that encourage children to explore and practice new skills.

Conclusions

In the 4 decades since the concept of epigenetics was first proposed, the fundamental tenets of pediatric growth and development have been rewritten. Recent technological advances in brain research, along with social research in how children learn, have shown that exposure to a few critical factors — nurturing, nutrition, and environmental exploration — from conception throughout early years of life, can establish a foundation for life-long strength. The challenge going forward is how to transform burgeoning scientific findings into integrated programs for the prevention and mitigation of risk. Such interventions will guide parents, pediatricians, and policy makers in promoting strength in children world-wide (Wachs et al. 2014).
The World Bank and the World Health Organization have used one overarching term to describe the concept of “strength” as applied in this paper: “human capital”. Human capital is defined as being the cumulative knowledge, skills, resilience, and health that individuals acquire throughout their lives (WB 2020; WHO 2020b). The fields of economics and of public health recognize the idea of human capital, as it describes the factors that allow any individual to realize their full potential as productive members of society. Promoted effectively, rising human capital confers strength across a population. Conversely, loss of human capital during pregnancy, infancy, childhood, or adolescence is particularly devastating to any society, particularly those in developing regions (WB 2020; WHO 2020). Policies and programs that promote the full capacity of its children require sustained investment in nutrition, sanitation, health care, quality education, jobs and skills, as proposed in the WHO ‘s Global Targets 2025 (WHO 2020). The economic return on such investments made for the well-being of pregnant women and their children has been shown to be enormous, both in terms of financial capital and human capital among diverse international communities (Gertler et al. 2014; Heckman and Karaplapkula 2019, Heckman 2020).

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