Childhood growth, current age, and waist circumference predict biological reserve capacity, physical performance, and rapid aging in Bangladeshi women

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Abstract

Background The UK Bangladeshi community is socially disadvantaged, and many adults suffer from obesity, diabetes, and other chronic illnesses. Rapid aging has been noted.

Objectives Analyse biosocial trade-offs in growth, adult body composition, and reproduction, which are risk factors for age-related decline in physical performance, more rapid aging, frailty, and death.

Methods Sample: 40 Bangladeshi mothers (40–70 years old), one of their adult daughters (N=37, 18–36 years old) in the United Kingdom (UK), and 22 mother-daughter pairs of the same age range in Bangladesh (BD). Measurements: anthropometry, including knee height, migration, demographic history, education level, current menstruation (yes/no), and a 7-component lower body physical function score (PFS). Analysis: ridge regression and St Nikolas House Analysis (SNHA).

Results All the women are of short stature (x̄=150cm), with especially low knee height. Daughters who migrated to the UK have shorter knee height than daughters born in the UK. Marriage age was 16–18 years and total pregnancies of ∼6 per mother, ∼3 per daughter. UK mothers have higher fatness and lower PFS than BD women. Greater knee height predicts greater PFS, and that greater waist circumference and older age predict a lower PFS. SNHA finds that knee height is the most direct predictor of PFS.

Conclusion Adult knee height may serve as a sensitive indicator of early life physical and emotional well-being and predict physical performance, a risk factor for frailty and death. International migration of daughters is associated with poorer health status and physical performance at later ages.

Take-home message for students 1. International migration from Bangladesh to the United Kingdom is associated with social isolation, poorer health, lower physical performance, and greater risk for frailty. 2. Protecting and enhancing early life health may save national health systems considerable expense and may enrich the personal lives of older people and their families.

Introduction

The primary aim of this article is to investigate the effects of early life physical and emotional health, reproductive history (age at marriage, pregnancies, birth), and later life body composition (muscularity and fatness) on physical performance. We focus on a group of Bangladeshi women, 40 to 70 years old, and one of their adult daughters living in Bangladesh or in the United Kingdom. The findings of the present analysis are for these specific women and for their histories of birthplace, upbringing, migration (or not), age at marriage, age at first birth, subsequent births, and their body measurements at the time of testing their physical performance. However, many of the findings should apply to all women. This is so because the variables considered are common to virtually all human groups. The findings are important because many migrant women from lower income nations experienced much physical, material, social, economic, political, and emotional adversity in the lives. These adversities increase the likelihood of poor physical performance at an earlier age, relative to more advantaged groups of women. Poor physical performance is a reliable proxy for current health and a reliable predictor for the onset of frailty and mortality (Guralnik et al. 1994; Guralnik et al. 2000; Ferrucci et al. 2002). As stated by one of the leading research groups, "The assessment of physical functioning and disability is a critical component in the evaluation of older persons in both clinical and research settings" (Guralnik et al. 1994).

Specifically, we test two hypotheses, 1) greater knee height predicts higher levels of physical performance at later ages, and 2) the strength of this prediction is moderated by age at marriage and first reproduction, with earlier marriage and first birth leading to lower levels of physical performance at later ages.

There are several scientific and pedagogical strengths of this article. First is the use of life history theory to examine trade-offs between early life growth, reproduction, adult body composition, and physical performance. Second, the methods include the use of knee height, measured in adults, as a biomarker for physical and emotional health and well-being during the first decade of post-natal life. Associations are explored between the growth of knee height and quality of life factors, such as international migration from Bangladesh to the United Kingdom, reproductive history, including age at first reproduction and total number of pregnancies, and the rate of aging for a group of older mothers and their adult daughters. Third, the international context of Bangladeshi migration adds social, economic, political, and cultural dimensions to our analyses that are shared with many other populations around the globe. Fourth, the theoretical approaches to data analysis and interpretation include biological reserve capacity and a life course model of growth, maturation, and health. Together, the theory, methods, analyses, and findings contribute to the improvement of knowledge regarding several factors and process of health, well-being, and aging from birth to later adulthood.

Theoretical framework

Four intersecting frameworks guide this research: 1) Life history theory; 2) a life course model of growth and maturation; 3) biological reserve capacity; and 4) knee height as a proxy for early life material and emotional condition for growth.

1. Life history theory is a field of biology concerned with the strategy an organism

uses to allocate its energy toward growth, body maintenance, defence against infection, reproduction, raising offspring to independence, and avoiding death (Bogin and Smith 2012; Varea and Bernis 2013). For a mammal, it is the strategy of when to be born, when to be weaned, how many and what type of pre-reproductive stages of development to pass through, when to reproduce, and when to die. Living things on earth have greatly different life history strategies and understanding what shapes these histories is one of the most active areas of research in whole-organism biology. The life history approach attempts to unravel the reasons why different species of animals follow different sequences of growth, development, and maturation and why new life stages evolve, such as the childhood and adolescence stages of humans (Bogin 2021a). The nature of biological growth, development, and maturation is often best understood in terms of life history strategies for efficient self-health, reproduction and offspring survival (Cole 1954; Stearns 2004). A synopsis of human post-natal life history stages of growth, development, and maturation is given in Text Box 1.

Text Box 1: Human post-natal life history stages As explained in the main text, the present research focuses on the 'Early years' of the developmental pathway (the large arrow in Figure 1). Shown below the large arrow is an 'enlargement' of these 'Early years' divided into several stages of biological life history – infancy, childhood, juvenile, and adolescent. Detailed definitions of these life history stages may be found elsewhere (Bogin et al. 2018; Bogin 2021a). Briefly, these stages may be defined in terms of height growth velocity and in terms of feeding behaviour. A neonatal period from birth to about 28 days encompasses the transition from prenatal to postnatal life. Then begins the infancy stage, which continues to age 30–36 months and is characterized by feeding via lactation, with complimentary foods added by the end of the first year. The transition to childhood is characterized by the termination of maternal lactation and the completion of deciduous tooth

eruption by the infant. The limitations of a deciduous dentition and small digestive system require that children eat easy to chew and nutrient dense foods. Older members of the social group acquire, prepare, and provision these foods to children. This style of cooperative care frees the child's mother from lactation and much care and feeding of the child. The mother may then devote her resources to a new pregnancy and lactation of a new infant.
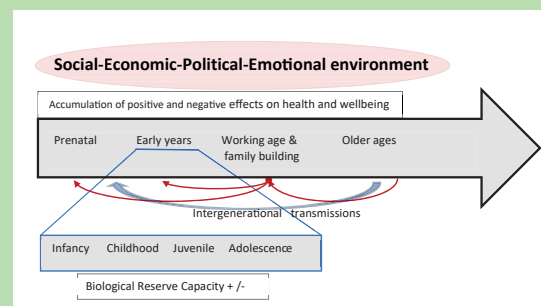

Figure 1 A conceptual framework of human biosocial development. Human development takes place within complex social-economic-political-emotional (SEPE) environments (Bogin 2021b). The SEPE environment includes kinship, marriage, and family systems (social), modes of food production, food distribution, and all other economic activities (economic), the systems for the administration of secular, religious, judicial, moral and other forms of power and social control (political), and systems to ensure security, self-worth, love, and hope (emotional) for people of all ages (Bogin et al. 2014). The SEPE environment regulates the distribution of resources needed for human development. Members of a society receiving more than an adequate share of these resources are likely to have positive health, wellbeing, and development. Receiving less than an adequate share of resources results in negative effects on health and wellbeing. These positive or negative effects accumulate during the life course. All human beings live in social groups which include multiple generations and, therefore, there are transmissions of biological (e.g., genetic and epigenetic) and SEPE resources between generations. Along the line labelled 'Intergenerational transmissions' there may be transfers of biological and SEPE resources, usually from older generations to younger generations. Younger people may also provide transfers to older generations and these transfers tend to increase from childhood to adolescence. Working age adults may provide substantial transfers to older age adults, as well as to younger generations. This is the case in many Bangladeshi families. The total impact of the SEPE environment and the intergenerational transmissions results in greater or lesser gains of 'Biological Reserve Capacity' during the Infancy-to-Adolescence stages of growth, development, and maturation from birth to adulthood.

The childhood stage ends at about age 6.9 years. The juvenile stage spans age 7.0 years to the onset

of the adolescent growth spurt, approximately age 10 for girls and age 12 for boys in healthy, well-nourished populations. Juveniles are sexually immature, but physically and mentally capable of providing for much of their own care. Human juveniles have the physical capabilities to eat the adult-type diet, as the first permanent molars and the central incisors have erupted by age 7 years. Human juveniles may produce some of their own food intake but still require provisioning to achieve energy balance.

Adolescence includes the years of post-pubertal growth, approximately ages 10–18 years for girls and ages 12–21 years for boys, including the adolescent growth spurt. Human reproductive maturity takes place during the latter part of the adolescent stage. Even when sexually mature and capable of producing enough food to exceed their own energy requirements, teenage boys and girls remain immature in terms of sociocultural knowledge and experience. These are required for successful adulthood in terms of reproduction and parenting. Human adolescents in all societies, both boys and girls, engage in many types of economic, social, sexual, and ideological apprenticeships that lead to greater adult reproductive and sociocultural success. Adolescence ends with the eruption of the third molar (if present) and the termination of growth of the skeleton.

The legend for Figure 1 describes features of the life span relevant to the present analysis, and is based on theory and cross-cultural research from anthropology, human biology, economics, political science, and related fields (Goodman and Leatherman 1998; Floud et al. 2011; Stinson et al. 2012). This trans-disciplinary approach to human health acknowledges the overarching importance of the complex social-economic-political-emotional (SEPE) environments in which human life span development takes place (Bogin 2021b). The model in Figure 1 organizes the impact of SEPE environments according to life stages. Shown are the chronological stages of the development of the person, from prenatal to older ages. Just below is a line representing the intergenerational transmission of biological and SEPE resources between developmental stages. These resources may be a combination of accumulated health, wealth, social prestige, education, and other biosocial characteristics. The effect of intergenerational transmissions on physical growth and maturation are well-known from studies of secular trends, in which the average height of different birth cohorts increases, or decreases, over time according to changes in the quality of the SEPE environment (Bogin 2013; Bogin 2021a; Bogin 2021b). Intergenerational transmission may be from older to younger generations or from younger to older, as when juveniles, adolescents, or younger adults contribute to the well-being of older age adults.

2. Life history theory relates to the important role that early life conditions play throughout the life course. Early life conditions affect the growth and maturation of the body especially during the infancy and childhood periods (birth to age 36 months and 37 months to 7 years) when the rate of growth is relatively fast, and the infant or child is dependent on others for feeding and protection. Early life nutrition and patterns of growth are known to affect the maintenance of physiological processes in adulthood, the risks of acute and chronic diseases, and the biological process of aging (Barker 2008; Crews and Bogin 2010; Thayer and Kuzawa 2011).

3. Another aspect of life history theory relates to biological reserve capacity (BRC), which may be defined as those somatic resources possessed by organisms which exist above the minimum required for necessary capacity, that is, the minimum needed to survive and reproduce:

$$BRC = TAC - NC \qquad (1)$$

where TAC denotes Total Achieved Capacity and NC denotes Necessary Capacity. Variation between individuals in their levels of performance for different kinds of physical tasks reflects their BRC reserve capacity. Systematic reviews of the literature finds that inadequate physical performance is significantly and consistently associated with diminished BRC as measured by disability, falls and mortality, and cognitive reserve capacity (CRC) as measured by cognitive impairment and institutionalisation (Ferrucci et al. 2002; Crews and Bogin 2010). Considerable costs

to individuals, their families and the larger society accrue from these outcomes.

The lowest box of the conceptual model in Figure 1 is labelled 'Biological Reserve Capacity'. Greater BRC acquired in early life allows greater investment in somatic maintenance and repair, which slows the rate of aging, delays the accumulation of risks for frailty, and allows for greater longevity survival (Crews 2003; Crews 2007; Finch and Crimmins 2004; Crimmins and Finch 2006; Larke and Crews 2006; Bogin 2009).

Human life history is unusual in that the stages of childhood and adolescence are evolutionarily novel (see Text Box 2), or at least far more highly developed and prolonged than in any other mammal, even the apes and monkeys. Other primate species develop through the infant, juvenile, and adult stages. The insertion of childhood and adolescent stages into human life history provide more time for growth, development, and maturation than any primate. If environments are favourable, with excesses of physical, biological, social, and emotional resources above those needed to maintain necessary capacity, then human beings have the potential for greater BRC at the start of adulthood and the initiation of reproduction than any other primate. Others have hypothesized that the tendency to greater BRC of humans at the onset of adulthood translates into the modal greater longevity of the human species than other primate species (Crews 2003). Adverse environments will cause a reduction of BRC, usually expressed in reduced body size, work capacity, cognitive functioning of young adults and their reduced longevity (Bogin et al. 2007).

Accordingly, human BRC is accumulated during the stages of growth, development, and maturation as shown in the following conceptual equation (Eq. 2):

$$BRC_t = \text{gestation} \pm \text{infancy}$$
$$\pm \text{childhood} \pm \text{juvenile}$$
$$\pm \text{adolescence} \pm \text{early adult}$$
$$- \text{later adult} \qquad (2)$$

BRC_t is reserve capacity at age=t, and the life history stages of gestation, infancy, etc. are developmental periods when RC may be gained or lost. This model assumes that maternal investment and BRC accumulation during gestation is positive only. Dire situations, in which embryonic or fetal reserves are depleted prior to birth, are likely to preclude survival. Life stages after birth may have positive or negative investment into BRC building, but the investments cannot be less than necessary capacity at any stage. For humans, BRC building may continue into early adulthood, ending by age 25–35 years when the onsets of senescent declines are noted in many body systems. This conceptual equation does not specify the units of BRC, that is, the way that gains or losses in BRC are calculated. In the present research, the method used for the estimation of accrued BRC in early life is based on the measurement of knee height. The rationale for this is explained below under point 4.

Women in in all societies and of virtually all socioeconomic status (SES) are likely to experience declines in somatic BRC with their first pregnancy. The demands of reproduction mean that BRC is lost due to pregnancies, lactations, and other maternal investments in offspring (Scholl et al. 1997; DaVanzo et al. 2008). Even for women of higher SES in the wealthiest nations, pregnancy, birth, and infant care entail some loss of BRC (Doblhammer and Oeppen 2003). Due to the loss of BRC with pregnancy and birth, the age at first reproduction for women is defined by some researchers as equivalent to the age at onset of frailty and senescence (Westendorp and

Kirkwood 1998; Doblhammer and Oeppen 2003; Larke and Crews 2006; Hayflick 2007; Hsu et al. 2021).

4. Knee height (KH) is the proxy for accrued BRC in early life. The measurement of total stature is the traditional method for estimating BRC, as completed height in early adulthood represents the cumulative history of all positive and negative experiences (Bogin 2021a). Adult height, however, does not pinpoint when those experiences occurred, because the human capacity for catch-up growth after a period of under-nutrition or illness, and a growth period lasting 20 or more years, mean that height at early adulthood may not reflect early life (i.e., infancy, childhood, juvenile stages) conditions (Wit and Boersma 2002). Interviews and questionnaires of adults may help understand early life conditions, but memory is selective, and people often have reasons to withhold or distort information.

It is better to have a quantifiable, objective measure of health status for early life. KH is one such measure. KH in adult women and men may be used to estimate the building of BRC during infancy, childhood, and the juvenile stages of growth, that is, between birth and puberty. Human body proportions at birth are typified by relatively short legs and a relatively long head, neck, and trunk. Between birth and puberty the leg grows faster than the upper body and the tibia grows faster than the femur (reviewed in Bogin and Varela-Silva (Bogin and Varela-Silva 2010)). As a result, the tibia is exposed to the qualities of the environment for post-natal growth, meaning the 'material and moral conditions' for growth as phrased by (Tanner 1987), for a longer time and with greater sensitivity than any of the other major long bones contributing to stature. It has been known since the 1950s that in adverse environments total stature is reduced, with legs more affected than the upper body

and the tibia more compromised than the femur (Leitch 1951; Bogin and Varela-Silva 2010; Shirley et al. 2022). Operationally, KH is a near-constant linear value from early adulthood until death – it does not 'shrink' as does total stature with age. Measurement of KH in adults, especially older people, provides a proxy for total skeletal growth early in life (Chumlea et al. 1985; Chumblea et al. 1998). The consensus of research finds that shorter adult leg length, especially shorter tibial length, is related to poorer health in the first decade after birth and may be associated with accelerated frailty and aging, and a reduction in longevity (Chumlea et al. 1985; Prothro and Rosenbloom 1993; Roubenoff and Wilson 1993; McEnry and Palloni 2010; Prince et al. 2011).

Methods

Participants

This article is based on a research project called 'Migration, Nutrition and Ageing Across the Lifecourse in Bangladeshi Families: A Transnational Perspective (MINA)' (Thompson 2013; Thompson et al. 2012). Project MINA investigated two generations of Bengali women in the United Kingdom (UK) and Bangladesh (BD). The UK sample included 40 mothers (40–70 years old) who migrated to the UK, and one of their daughters (17–36 years old) born in the UK (n= 20) or in BD (n=17), and 22 mother-daughter pairs of the same two age groups in BD. The UK mothers and daughters resided in Cardiff, Wales and originated from the Sylhet region of BD, where all the BD participants resided. As a UK ethnic minority, many of the Bangladeshi community are socially disadvantaged and suffer from high levels of disability, obesity,

type-2 diabetes, and cardiovascular disease and rapid aging (Nazroo 2004; Sproston and Mindell 2006). Little is known about the causes. Project MINA took an interdisciplinary approach toward discovery of the causes. The research team was comprised of specialists from health psychology, ethnobotany, sociology, nutrition, kinesiology, human factors/design, photography, and anthropology.

The field research for the present article was conducted between 2009–2011. The following description about Bangladeshis in the United Kingdom (UK) and in Bangladesh is based on information from the years of fieldwork. According to the UK Office for National Statistics the population of England and Wales in mid-2009 numbered 54.8 million people and was comprised of the following ethnic groups: White, British 83.35%, Asian or Asian British 5.87%, Black or Black British 2.81%, Mixed 1.80%, and Chinese 0.82%. In the UK the term 'Asian' refers to people from the former colonies of India, Pakistan, and Bangladesh. The total 'Asian' population in the UK in 2009 was 1.4 million people and Bangladeshis numbered 392 thousand or 28% of all 'Asians'.

In the UK the Bangladeshi population is one of the fastest growing ethnic groups. UK Bangladeshis are amongst the most socially disadvantaged and deprived ethnic groups (Ahmed and Rees Jones 2008). They have poorer self-reported and measured health status indicated by higher rates of disability, centralised obesity and chronic diseases such as type-2 diabetes and cardiovascular disease (Sproston and Mindell 2006). Older Bangladeshi women are particularly affected as they play a lead role in caretaking for multiple generations within relatively large extended families, and many women struggle to cope with the complex challenges of ageing, poverty, racism, and social exclusion (Gardner 2021; Phillipson et al. 2004).

Bangladeshi settlers to the UK first arrived in the 19th century but the major migrations occurred during the 1950s and 1960s. As Ahmed and Rees Jones (Ahmed and Rees Jones 2008) explain, "These were mainly male migrants who came with a view of temporary settlement but as time passed they settled for the long term, and sought to bring wives and families over from Bangladesh."Approximately 95% of Bangladeshis in the UK originate from the Sylhet region in the northwest of Bangladesh. Núñez de la Mora and colleagues (Núñez-de la Mora et al. 2007) reported that UK Bangladeshis are a homogeneous group in terms of many biosocial characteristics such as their Sylhet origins, shared socioeconomic status, "…low rates of intermarriage with other ethnic groups, thus reducing genetic 'noise,'…similar histories of migration, and…multigenerational population that allows for recruitment of individuals who entered Britain at different life stages (infancy, childhood, and adulthood)." Núñez de la Mora and colleagues continue by writing that, "Most Bangladeshi migrants originate from relatively affluent, land-owning classes in Sylhet who live in solid dwellings, have access to good nutrition, and have low levels of energy expenditure…They are not, therefore, comparable to the rural, malnourished populations…" of Bangladesh. Greater detail about the history of Bangladeshi immigration to the UK is given in Text Box 2.

Text Box 2: Ships, factories, and restaurants: Sylhetis on the move (From Katy Gardner (Gardner 2008). The material here is quoted from pages 480–481, with permission of the author)
Whilst today most regions of Bangladesh send migrants to work as labourers in the Middle East and Southeast Asia, for many generations Sylhetis have monopolized migration to Britain. Indeed, Sylhet's special relationship with the UK is just one reason why the district is seen by many Bangladeshis as significantly different from the rest of the country. Over the nineteenth cen-

tury and into the twentieth, many Sylheti *lascars* [meaning an Asian militiaman or seaman, especially those from the Indian subcontinent, serving the British] 'jumped ship' in London, where they stayed, seeking work as peddlers or in London's hotels and restaurants (Choudhury 1993). Although originally men from districts such as Noakhali and Chittagong were also *lascars*, by the twentieth century Sylhetis dominated (Choudhury 1993). Crucially, particular individuals dominated the recruitment of labour, leading to a 'chain' effect whereby men from particular villages and lineages gained employment through the patronage of their relatives and neighbours.

The vast majority of Sylhetis first came to Britain in the 1950s and 1960s when the second phase of migration to the UK took place. Prompted by a labour shortage after the Second World War, the British authorities actively encouraged labour migration from previous colonies and thousands of migrants embarked for the UK (Adams 1987; Choudhury 1993). Most Sylhetis initially found employment in heavy industry. These men were 'transnationals' par excellence: they worked and lived in Britain, but returned home as often as they could, where they were still heavily involved in social networks of kinship and village community.

Over the 1970s and into the 1980s, conditions started to change. Britain's heavy industry was in decline and many Sylheti men moved to London to seek employment in the garment or restaurant trades. Crucially, a growing number started to bring their wives and children to the United Kingdom (Peach 1996). This shift was partly the result of changing immigration laws, which many rightly feared would soon make primary migration to Britain (without it involving marriage to a British citizen) increasingly difficult. It also reflected wider changes in the areas where many Bengalis were settled, in which mosques, shops selling halal meat, and other community facilities were becoming established. Today, the Bangladeshi population is one of the youngest and fastest growing in Britain and the process of family reunification is largely complete. If not classed as a 'family dependant', it is currently extremely difficult to obtain an entry visa to Britain from Sylhet. Indeed, figures from the British High Commission in Dhaka show that of the Bangladeshis seeking work permits over 2005–6, 90 per cent were from Sylhet and the vast majority were refused.

Transnational marriage

Increasingly a new form of movement between Sylhet and Britain, is taking place. Whilst in the 1970s and 1980s it was mostly wives who travelled to the UK to join their husbands, today almost as many men apply for settlement visas to join their British based wives. Foreign Office figures show that in 2005, 1,530 settlement visas were granted to Bangladeshi grooms (with 330 refused), in contrast to 2,133 issued to brides (with 590 refused). These figures have remained relatively stable since 2001.

Despite the relative affluence of Bangladeshis who migrated to the UK, Bangladesh is a low-income nation with many problems that negatively impact health. The per capita gross national product of Bangladesh amounts to less than 2% of that of the UK. In Bangladesh, child and maternal malnutrition are common. At the time of the MINA project research there was a 41% prevalence of underweight (weight-for-age z-score <-2) among children aged less than five years and about 30% of women had a body mass index (BMI) of $<18.5 kg/m^2$ which is the cut-off value for thin/undernourished (Ahmed et al. 2012). There was also a high prevalence of deficiencies for iron, iodine, and other micro-nutrients among young infants, adolescent girls, and women (Ahmed et al. 2012).

As of 2011, life expectancy at birth for BD women was 69 years compared with 82 years in the UK, a difference of 16%, and the mortality rate for infants and children under five years old per 1,000 live births was 46 for Bangladesh and only 5 for the UK (World Bank 2022). Many Bangladeshi women in the UK who were born in Bangladesh report one or more child deaths, as shown in Table 1 for our sample, indicating that life in Bangladesh is precarious even for these relatively affluent families. Poor sanitation due to inadequate sewage and waste disposal systems, limited water treatment, and the poor quality of health care characterize most of the Sylhet region. In addition, there are seasonal floods which increase the likelihood of

infectious disease and scarcity of potable drinking water. People infected with intestinal parasites are ubiquitous in both Sylhet and in recent migrants to the UK.

Wales is a constituent country that is part of the United Kingdom. It is bordered by England to the east and the Irish Sea, Celtic Sea, and Bristol Channel to the north, west and south. Cardiff is the capital city. In 2021 the population of Wales totalled 3,107,500 with 481,000 residents in Cardiff and 1,097,000 people in the greater Cardiff-Newport metro region. An overview of demographic, economic and social conditions for Bangladeshis in Cardiff may be found in reports from Project MINA (Thompson et al. 2012), from the Cardiff City Council (Cardiff and the Vale of Glamorgan 2017), and from news media (Day 2013). According to these sources, the region of Cardiff where most of our Bangladeshi participants live is characterized by social deprivation, high levels of unemployment, high rates of reported crime, poor educational achievement rates, high levels of housing benefit claimants, high mortality rates and a high percentage of low birth-weight babies.

Measurements

MINA was a cross-sectional study and participants were seen at data collection events or in their homes between the years 2009–2011. Several types of social, psychological, health, nutrition, and physical activity questionnaires were administered. Detailed migration histories were collected. These questionnaires and interviews were conducted by well-trained field workers who were native speakers of the languages of Bangla, Sylheti, or English as appropriate. The interviews in Bangla or Sylheti were translated into English. The data from these questionnaires and interviews, as well as from all measurements described below, are available via Thompson (2013).

Each participant contributed a measurement of bone density, estimated by ultrasound of the calcaneus bone of the foot (heel bone) and anthropometry. The later included height, weight, sitting height, knee height, and waist circumference. All the anthropometric measurements (except knee height, see below) were taken by one well-trained member of the MINA team who followed standard protocols and used recommended equipment (Lohman et al. 1988).

Knee height (KH) was measured with a Harpenden anthropometer using a method modified from the NHANES anthropometric manual (NHANES III 1988). The participant sat on a purpose-built stool with the soles of both feet on the floor, the lower back and shoulders against the wall, looking straight ahead, with the lower leg as perpendicular to the floor as possible (90-degree angle to the floor). KH was measured as the distance from the floor to the proximal border of the patella (top of the kneecap). Our method avoids contamination of the measurement with soft tissue, especially fat, which has been shown to artificially inflate other linear skeletal measurements such as sitting height (Bogin and Varela-Silva 2008; Bogin and Varela-Silva 2010).

A lower limb physical function score (PFS) was assessed by the Guralnik Short Physical Performance Battery (SPPB) (Guralnik et al. 1994). The SPPB is composed of tests for standing balance, walking speed, and ability to rise from a chair without use of the arms. Each of these tests is performed in the presence of an observer who records and scores the ability to perform the movement, the number of movements completed, and/or the time taken for each movement. The SPPB has demonstrated a high level of reliability and validity for adults aged 65 or older to estimate lower body physical performance, frailty, and risk for mortality (Wang et al. 2020). Both

the Bangladeshi mothers and daughters were assessed with the SPPB to provide a continuum of age changes in physical performance.

Statistical analysis

Descriptive statistics were used to estimate means, standard deviations, frequencies, and percentages for all variables for categories of mothers, daughters, country of birth and current country of residence. T-tests or ANOVA were used to estimate statistical significance between comparison groups. Statistical significance was set at $p<0.05$. Ridge regression was used to assess the relative influence of predictor variables on outcome variables. Ridge regression is used because many of the independent variables in the MINA data set are highly intercorrelated, for example total number of pregnancies and total number of living offspring has a correlation coefficient of $r=0.85$. All the anthropometric variables have similarly high correlations. Due to these multicollinearities, it is not possible to obtain stable estimates for the regression coefficients via ordinary least squares methods. Ridge regression adds a constant, called *lambda* to the diagonal of the correlation matrix, which is then re-standardized so that all diagonal elements are equal to 1.0. The off-diagonal elements are divided by the constant. In other words, ridge regression artificially decreases the correlation coefficients so that more stable estimates (*beta* coefficients) can be computed. The value of lambda can vary from zero to infinity. When it is zero the analysis is, essentially a conventional least-square multiple regression. A large *lamda* value (about 4 or greater) eliminates most or all associations between variables. A *lambda* of 0.10 was used in the present analyses.

Another method used to assess the associations between independent and dependant variables is the relatively new technique of St Nicholas House Analysis (SNHA). The name is derived from a Christmas game played by children in Germany. The SNHA method also deals with multivariate datasets with multicollinearity. SNHA calculates ranked correlations (from most to least correlated) and produces a network graph for the visualization of these associations in (Groth et al. 2019; Hermanussen et al. 2021). The SNHA network graph arranges the independent and dependent variables as nodes and the associations between them as edges. Edges direct the order of associations from one node (variable) to the next one. The network graph is arranged in hierarchy of correlation coefficients based upon a reversion chain of the correlation coefficients' r^2 values, ranked from strongest to weakest. In essence, SNHA provides a directed graph that has a topological ordering from independent variables with 'earlier' to 'later' influence on the dependent variables. The performance of SNHA has been shown to be superior to other network graph techniques, most of which use partial correlations for analysing bands and hubs (Groth et al. 2019). The calculations were conducted with the programming language R (R Development Core Team 2022) version 3.6.3 which is a free software under the terms of the Free Software Foundation's GNU General Public License in source code form. The corresponding R-code is available on request from Dr. Detlef Groth, University of Potsdam, Germany.

Results

Demographic characteristics

No difference in mean age exists between the UK and BD mothers, but BD residing daughters were statistically younger

than UK residing daughters (Table 1). All mothers were married or widowed and had completed fertility. Mothers in both countries have a statistically equal number of pregnancies, number of live born children, pregnancy loss, and relatively high fertility. Age at marriage and all fertility data of the daughters are incomplete estimates, as 24 of 37 UK-living daughters were married or divorced and only 7 of 22 BD-living daughters were married at the time of data collection. The lower number of married daughters in BD reflects their younger age and our decision to interview the BD-living women in the mother's home – married BD daughters would be living with their mother-in-law. Consequently, no value for 'age at final birth' is given for daughters.

Anthropometric status

Anthropometric values are reported without adjustment for age (Table 1). All women are of short stature with a global mean of 150.5cm (sd= 6.4). Daughters are, on average, taller than their mothers, but the difference is not statistically significant. KH of daughters is significantly greater than mothers in Cardiff and Bangladesh. To better compare the body proportions of these women, the sitting height ratio was calculated (SHR = [sitting height/height] x100). This ratio standardizes for differences in height: a smaller value indicates relatively longer legs for a given stature. There is no significant difference in SHR between mothers and daughters. UK women have significantly greater SHR than BD women, suggesting that UK women have relatively shorter legs for their height.

Daughters were divided into three groups: 1) born and living in the UK (UK-UK, n=20), 2) living in the UK and born in BD (UK-BD, n=17), and 3) born and living in BD (BD-BD). The mean age of migration for the UK-BD daughters is 8.2 (+/-7.5)

years, with a lower quartile of 3.0 and upper quartile of 12.0 years of age. The UK-UK and BD-BD daughters have significantly greater KH than the UK-BD daughters (Figure 2, Table 2). UK-UK mean height is 3.8cm greater than the UK-BD mean (p <0.05). Sitting height means do not differ, indicating that all of the difference in stature between the two groups of daughters is due to leg length. Further analysis indicates that 2.0cm (53%) of total height difference is due to KH (tibia + foot) and 1.8cm is due to thigh length. This is consistent with other research indicating that as stature increases the tibia elongates more than the femur (Duyar and Pelin 2003).

UK-residing women have higher rates of overweight and obesity than BD-residing women as indicated by body weight, waist circumference (WC) and BMI (Table 1). UK mothers are especially overweight. Conversely, about one-fifth of all BD women are underweight.

Results from the SPPB indicate that total score declines with age for all women (Figure 3). All participants attempted each task of the test. The daughters' total scores decline with age, which was unexpected as the SPPB is designed to measure declines in physical performance for adults aged 65 years and older. Until age 65 all participants are expected to score a 'perfect' 12 on the SPPB. BD mothers have significantly higher total scores than UK mothers. The average score for the UK mothers falls below the test's cut-off value of 7.0 for an increased risk of frailty. Indeed, 21 individuals fall below 7.0, 6 are at or below a score of 2.0 with 2 women scoring '0', meaning that they were unable to perform any elements of the test.

Knee height, physical performance, and biological reserve capacity

The influence of demographic, anthropometric, and nutritional status variables on physical performance of the mothers was estimated by ridge regression. The model and the estimates with a *p*-value of 0.05 or less are shown in Table 3. Prior to the ridge regression analysis, the correlations between al variables were examined (Supplemental Table 1). Where high multi-collinearity existed between variables only one of those variables was chosen. All the fatness variables, for example, were correlated at $r = 0.9$ or greater. Waist circumference was chosen as the fatness variable because it is often the most sensitive risk factor for metabolic disease and ageing in South Asians (Cameron et al. 2010).

Older age for mothers is most strongly predictive of a lower physical function score (the negative sign of the standardized beta for the PFS, Table 3). Greater KH is the next

Table 1 Characteristics of the participants given as mean values (standard deviations) or percentages. All values are as measured with no statistical adjustment for age differences.

	Cardiff Mothers (n=40)+	Bangladesh Mothers (22)	Cardiff Daughters (37)++	Bangladesh Daughters (22)
Age (yr)	55.3 (8.1) Range=40-69	51.9 (8.8) Range=40-70	27.4 (5.5)** Range=17-36	22.8 (5.1) Range=17-35
Age when married (yr)	16.3 (2.7)	16.5 (3.3)	18.7 (2.3)	18.4 (3.8)
Age at 1st birth	20.8 (4.2)	23.2 (5.5)	21.3 (2.2) N=20	20.5 (2.6) N=6
Lag from marriage to 1st birth (years)	4.3 (3.9)	5.6 (5.7)	2.6 (1.4) N=20	1.8 (3.0) N=6
Age at final birth	34.4 (6.7)	35.8 (5.3)		
Total pregnancies	6.6 (2.0)	5.6 (2.1)	2.9 (1.0) N=20	2.9 (2.3) N=7
Number of living children	5.6 (1.8)	4.9 (1.6)	2.6 (0.9)	2.7 (1.5)
Height (cm)	147.7 (6.2)	148.8 (5.7)	153.2 (5.8)	152.7 (6.0)
Sitting height (cm)	77.4 (3.7)	76.4 (3.4)	81.4 (2.4)**	78.2 (3.0)
Sitting height ratio	52.4 (1.5)	51.3 (1.3)	53.2 (1.4)	51.2 (2.2)
Knee height (cm)	45.9 (2.4)	46.9 (2.4)	46.7 (2.5)	48.2 (2.3)
Weight (kg)	66.0 (13.4)*	53.5 (15.2)	64.5 (14.5)**	50.8 (10.6)
Waist (cm)	97.9 (9.6)*	82.5 (14.0)	82.4 (13.0)**	72.4 (8.3)
BMI (kg/m^2)	30.1 (5.2)*	24.1 (6.4)	27.5 (5.7)**	21.8 (4.4)
BMI category¶ Underweight Acceptable risk Increased risk High risk	0% 5% 30% 65%	13.6% 40.9% 18.2% 27.3%	0% 25.0% 22.5% 42%.5	22.7% 40.9% 22.7% 13.6%
Physical function score	6.3 (3.0)*	9.4 (1.9)	10.8 (1.1)	11.2 (0.8)

+Mean age at migration = 30 years
++ 20 born in UK and 17 born in Bangladesh; mean age at migration = 8 years
¶WHO BMI cut-off categories for South Asians: Underweight
<18.5; Increasing but acceptable risk 18.5-23; Increased risk 23.1-27.5; High risk >27.5
 Physical function score, maximum score = 12; <7 indicates high risk for frailty & poor health outcomes.
*Means for the mothers are significantly different $p \leq .01$
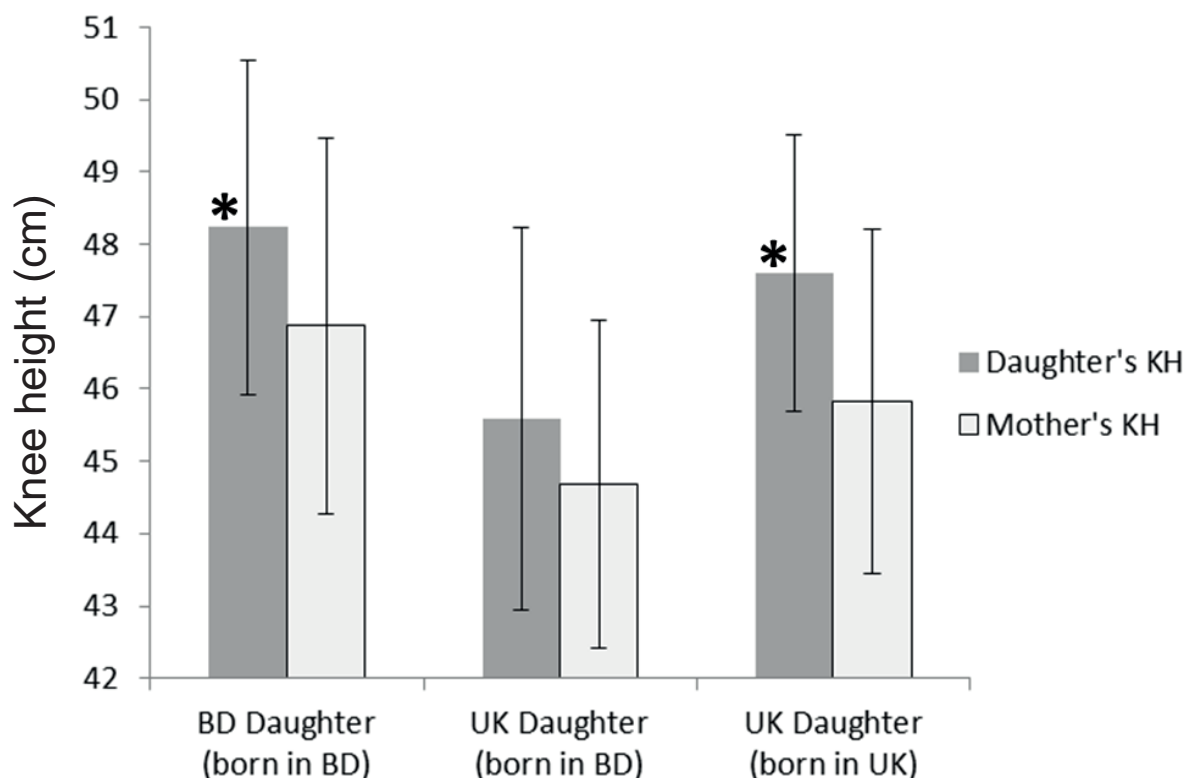**Means for the daughters are significantly different $p \leq .01$

Figure 2 Knee height (KH) meaured in centimeters (cm) of daughters and mothers. The asterisks (*) indicate that Bangladesh-living daughters and UK-living daughters born in the UK have significantly greater KH than UK-living daughters born in Bangladesh (p = 0.01).

most predictive of a higher PFS. Greater waist circumference predicts lower PFS. Taken together, these variables account for 22% of the variance in score for the SPPB among the mothers. This value is the *adjusted R^2*, which is a modification of R^2 that corrects for the number of explanatory terms in a model and better estimates the amount of variance explained by the model for the population instead of just the sample (Field 2009).

A ridge regression analysis for the daughters found results similar to those for the mothers (findings not shown). Older age is predictive of lower PFS and greater KH is predictive of higher PFS. Greater stature predicts lower PFS, but this is likely due to multicollinearity with KH as the correlation between height and PFS is only $r = 0.06$. There is a significant effect of migration status, with UK-BD daughters having lower PFS than UK-UK and BD-BD daughters. The regression model for the

Table 2 Means (+/- sd) and t-tests for height, sitting height, and knee height (all in cm) of UK living daughters born in Bangladesh (UK-BD, n=17) or in the UK (UK-UK, n=20).

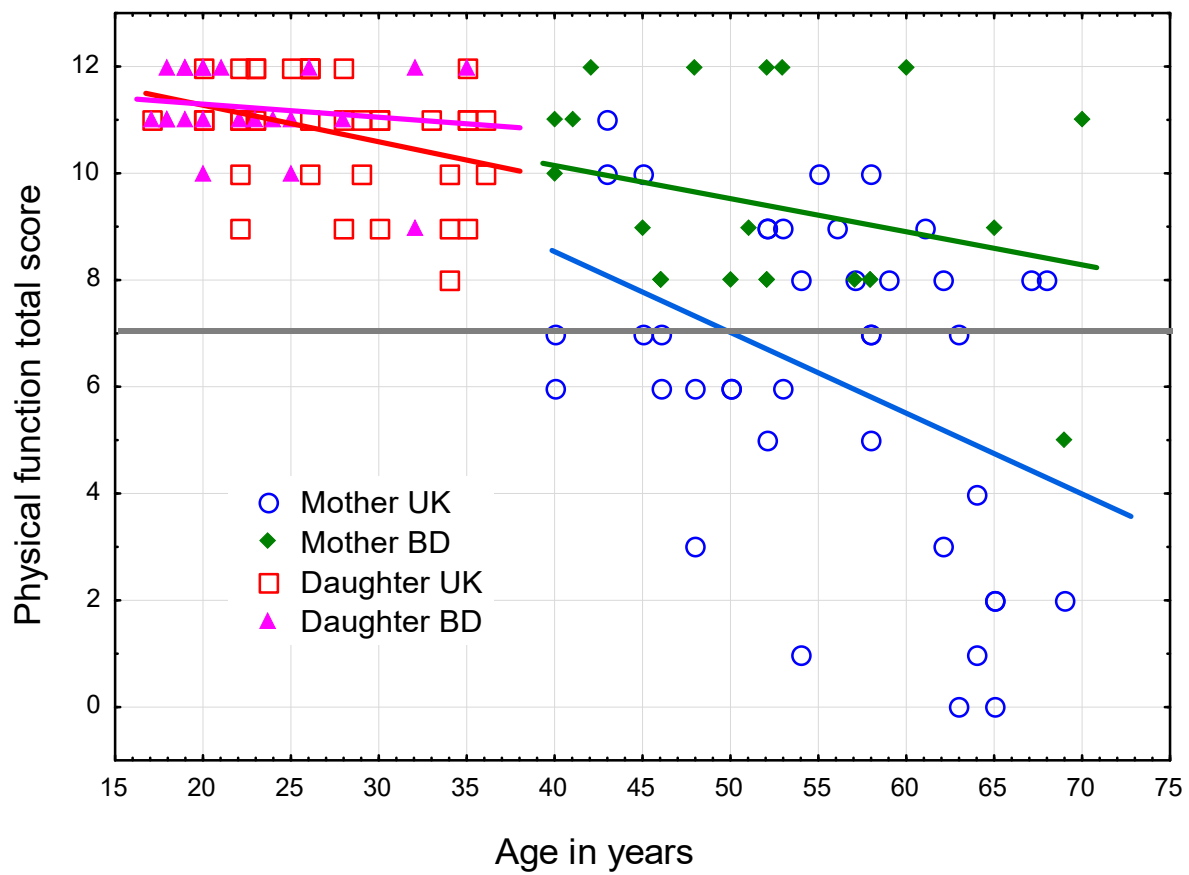|	UK-BD	UK-UK	t-value	df	p
	Mean (sd)	Mean (sd)			
Height	151.0 (6.2)	154.8 (5.0)	-2.09	35	0.04
Sitting height	80.9 (2.3)	81.7 (2.4)	-1.05	35	0.30
Knee height	45.6 (2.7)	47.6 (1.9)	-2.69	35	0.01

Figure 3 Change in the total score of the Guralnik Short Physical Performance Battery (Guralnik et al. 1994) by age. Scores below 7 (the dotted line) indicate high risk for frailty and poor health outcomes.

daughter's accounts for 21% of the variance (*adjusted R²*) in PFS.

St Nicholas House Analysis

The SNHA was performed on a larger set of variables than for the ridge regression and

Table 3 Ridge regression results for predictors of total score for the Guralnick Short Physical Performance Battery for the Bangladeshi mothers. Variables entered into the regression are current age, age at first birth, age at last birth, still menstruating (yes/no), height, knee height, waist circumference, arm muscle area, education level, age when married, total pregnancies, total living children, unsuccessful pregnancies, time lag between marriage and first birth. Statistically significant predictors ($p < 0.05$) are shown in the table.

N= 52, R= 0.66, R²= .44, adjusted R²= .22§ , F(14,37)=2.02, p=0.04, *lambda* = 0.10						
	Standardized Beta	SE	beta	SE	t(38)	p-value
Intercept			16.29	11.53	1.41	0.16
Current Age	-0.54	0.17	-0.20	0.06	-3.12	<0.01
Waist circumference	-0.35	0.15	-0.08	0.03	-2.42	0.02
Knee height	+0.38	0.18	0.49	0.23	2.11	0.04

§ corrects for the number of explanatory terms in the model and better estimates the amount of variance explained by the model for the population instead of just the sample (Field, 2009).

included variables for which there is high multicollinearity. This is possible because the SNHA algorithm uses pairwise absolute correlation values for all variables to find association chains where the order of correlations has both a forward chain and a reversed counterpart (see Supplementary Materials Figure S1). The SNHA algorithm evaluates all these association chains to create a graph to visualize positive and negative correlations within the extensive complicated matrix of interacting variables within the data set. The output of SNHA is a visualized spatial relationship between variables that is far less biased by multicollinearity than conventional correlation or regression analysis.

The SNHA results are shown in Figure 4. In this network graph the independent variables 'age' and 'knee height' are most closely associated with the dependent variable, score on the SPPB. The independent variable 'waist circumference' is more distantly associated with SPPB score and is mediated by the variables 'sitting height', 'height', and 'knee height'. The differences in results between the SNHA and ridge regression analysis are considered in the discussion section.

Discussion

Project MINA offers a novel perspective on ways in which early-life human growth, development, and maturation associate with later life physical performance, health, and ageing. Few other studies compare two human populations of the same ethnicity in terms of two generations and two locations – the home country and the 'diaspora'.

The findings reported here support the first hypothesis that pre-adult gains in biological reserve capacity, proxied by KH, predict higher levels of physical performance and

lower risk for frailty at later ages, proxied by the Guralnik Short Physical Performance Battery (Guralnik et al. 1994). Even though the SPPB is designed for women 65 years and older, we note age-related declines in physical performance for all participants. Lifestyles in BD versus UK and the timing of migration may explain the patterns of physical performance in our participants. Interviews and ethnographic observations with participants indicate that BD-living mothers and daughters perform more daily physical activity related with lower body strength and flexibility, including walking outdoors, carrying bundles, taking stairs, doing housework without mechanical/electrical appliances, and squatting as a standard position when cooking and eating. Several BD-living families had small agricultural holdings and tended livestock, while others were relatively wealthy, and activities were predominantly household-related in nature. These types of moderate to vigorous physical activities are recommended to prevent losses in physical performance (Denvir and Gray 2009; Department of Health 2011). In contrast, the Health Survey for England reports that Bangladeshi women living in the UK have the lowest self-reported levels of physical activity of all ethnic groups (Sproston and Mindell 2006).

Our results justify the use of knee height as a biomarker of acquired biological reserve capacity. The difference in KH between the UK-residing daughters born in BD versus those born in the UK cannot be explained as simple genetic inheritance. When mothers and daughters of the two groups were compared it was found that only 53% of the mothers of BD-born daughters had a shorter KH than the daughter. In contrast, 80% of mothers with UK-born daughters have a shorter KH than their daughter. This is a biologically significant difference as well as a statistically significant difference (p=0.04). It seems most likely that
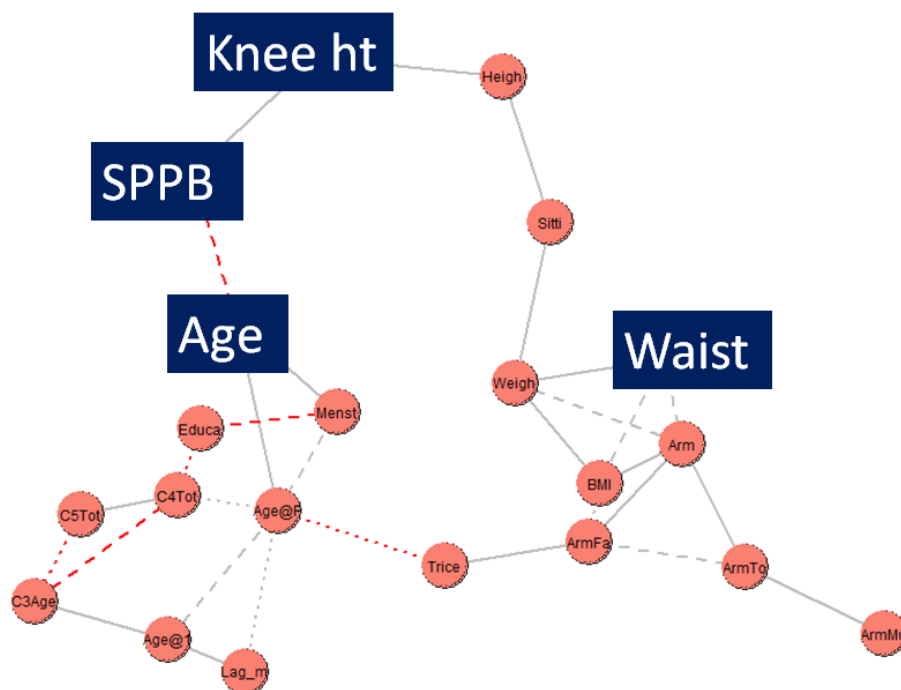
Figure 4 St. Nicholas House Analysis network graph of the associations between the dependent variable SPPB (score on the Short Physical Performance Battery) and the independent variables 'Age' (age at time of measurement), 'Knee ht' (knee height), 'Heigh' (height), 'Sitti' (sitting height), 'Weigh' (weight), 'Waist' (waist circumference), 'Arm' (mid-upper arm circumference), 'BMI' (body mass index), 'Armfa' (arm fat area), 'ArmTo' (arm total area), 'ArmMu' (arm muscle area), 'Trice' (triceps skinfold), 'Age@F' (age at first birth), 'Menst' (current menstruation, yes/no), 'Educ' (education level), 'C4Tot' (total number of pregnancies), 'C5Tot' (total living offspring), 'C3Age' (age at marriage), 'Age@1' (age at first birth), 'Lag_m' (number of years between marriage and first birth). The statistically significant variables are in BOLD in this list and highlighted in the figure.

prior to migration to the UK the BD-born daughters experienced higher levels of stressors that delay and reduce skeletal growth than did the UK-born daughters. These stressors may have been a combination of nutritional deficiency, infectious disease exposure (including parasites), and socioeconomic-emotional factors. In particular, mothers and their children who eventually migrated to the UK were often left at home in BD for one or more years after the husband/father migrated. The eventual migrants report after husbands/fathers left they experienced declines in standard of living and considerable feelings of insecurity in BD. These types of adverse early life experiences are reported in another study of 19 to 39-year-old Bangladeshi women who migrated to London at different ages (Núñez-de la Mora et al. 2007). These researchers also reported that those migrants who spent their pre-pubertal years in the UK had higher progesterone levels and greater ovulatory frequency than those who migrated at later ages (Núñez-de la Mora et al. 2008). Both higher progesterone levels and greater ovulatory frequency are

additional biomarkers of biological reserve capacity.

The second hypothesis, that the strength of this relationship between KH and physical performance is moderated by age at marriage and at first reproduction, is not statistically significant. Other research finds positive, negative and neutral effects between fertility variables and later life health (Westendorp and Kirkwood 1998; Doblhammer and Oeppen 2003; Mirowsky 2005; Hayflick 2007; Spence 2008; Kuningas et al. 2011; Lockhart et al. 2017; Hsu et al. 2021). Several of these studies find that lifestyle choices, such as smoking and alcohol usage, have major confounding effects on the fertility-health findings. Needed are studies of the total energy budget of women, including trade-offs with disease, socio-economic status, as well as the costs of investment in one's own offspring throughout their life, the children of others (e.g., nieces, nephews, adoptions), and grandchildren (Jasienska 2009).

The low physical performance scores and high fatness of the UK mothers are likely related to each other and are of clinical concern. Some Bangladeshi women appear to regard 'plumpness' as a sign of good health, greater wealth, and higher social status (Asghar et al. 2010). Nevertheless, research with South Asians in their homeland and in Europe finds a nearly monotonic increase in the incidence of type-2 diabetes and its comorbidities with greater waist circumference (Cameron et al. 2010; Feng et al. 2019).

Bangladeshi women, particularly immigrants, in the UK suffer from social isolation due to poor English language skills, fear of unfamiliar social environments, lack of knowledge of social services, and fear of the cold (Gray 2003; Merrell et al. 2005; Gardner 2008; Thompson et al. 2012). A survey of social isolation among minority people 65+ years old living in the UK finds that 40% of the Bangladeshis interviewed report 'often' feeling lonely. This contrasts with an average report of 8–10% for white British respondents (Victor et al. 2012). These researchers write that, "Loneliness is important because it is associated with a range of negative outcomes including low levels of physical activity, poor physical and mental health, elevated mortality, and increased use of services" (p. 78). Culturally tailored interventions, such as exercise/dance classes reserved for BD women only, may help alleviate both the lack of physical activity and loneliness. The MINA project provided a 'Bollywood-style' dance session at our data collection events, which were held at a community leisure centre familiar to the participants. Virtually all physically able Bangladeshi mothers and daughters participated and highlighted these dance sessions as a positive aspect of their involvement Project MINA.

A strength of our analysis is the use of both traditional regression and St Nicholas House Analysis. The conventional output of regression analysis is the *p*-value of an association between the dependant variable (SPPB score) and an independent variable. The ridge regression results were statistically significant for the independent variables 'current age' ($p<0.01$), 'waist circumference' ($p=0.02$), and 'knee height' ($p=0.04$). This type of statistical significance may be called '*p* wisdom', but the value of such '*p* wisdom' has been questioned (Amrhein et al. 2019). SNHA overcomes some of the concerns with '*p* wisdom' by estimating associations via the hierarchy and the priority of correlations in datasets with high multicollinearity. In the present case, SNHA reports that KH is the more important mediator of SPPB score than is waist circumference. This makes biological sense because the priority of growth is a person's KH, which is established during early life, between birth and

about age 10 years, while waist circumference is established in later life.

The major limitation to this study is the modest sample size. To overcome this limitation, we compared our findings for height, weight, fatness, and fertility to those reported from the larger sample of the Health Survey for England (Sproston and Mindell 2006). Our Cardiff sample of 17-to-36-year-old women averages one year older and 3cm shorter than same age Bangladeshi women in England. Cardiff women aged 40–70 years old average 3 years older and 4cm shorter. All the Cardiff women average 3kg heavier and 2 BMI points higher than Bangladeshi women in England. Mean waist circumference is 1cm less for 17-to-36-year-old women in Cardiff, but 6cm more for the Cardiff women aged 40–69 years. Shorter average stature and higher average weight, BMI, and, for the older women, greater waist circumference, are indicators of poorer early life and current health for the Cardiff sample.

Another limitation is that our method to measure KH is different from many other studies which makes direct comparison of KH data difficult, however relative lengths of the lower leg and total leg to total stature are possible to compute. A strength of our method is that KH is uncontaminated with soft tissue.

In conclusion, KH of adult women may serve as an indicator of early life health and a predictor of later life frailty risk. Increased frailty predisposes to a higher risk for falls, skeletal trauma, and poor overall health. Greater abdominal fat may impair physical function, lead to more frailty, and increase the risk of coronary disease and metabolic conditions such as type-2 diabetes. International migration is associated with social isolation, poorer health status, and greater frailty for both generations of Bangladeshi women. It is likely that these findings apply to other minority communities and have social policy and clinical relevance for added attention to early life health, nutritional balance, and emotional well-being. Protecting and enhancing early life health forestalls frailty in later life, may save national health systems considerable expense, and enriches the personal lives of older people and their families.

Acknowledgements

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Appendix

$$r_{A,B} > r_{A,C} > r_{A,D} \quad \text{and} \quad r_{D,C} > r_{D,B} > r_{D,A}$$
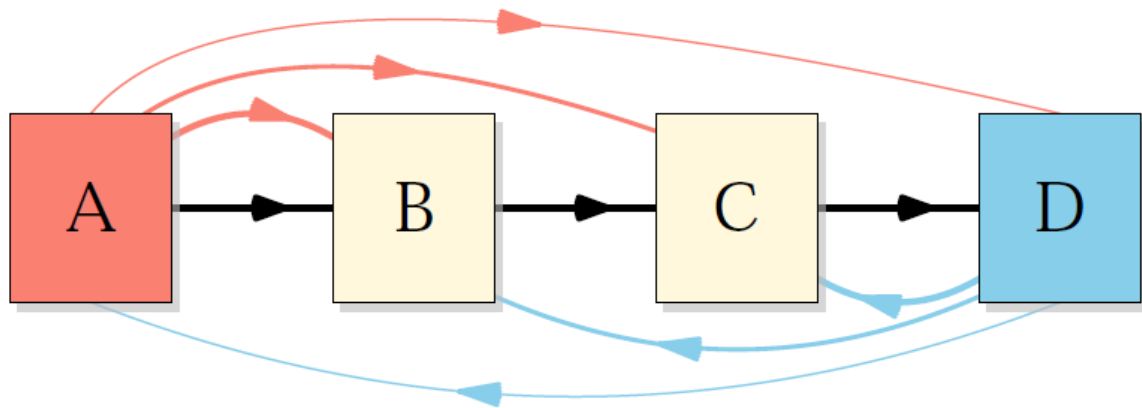

Figure S1 Model of St Nicholas House Analysis forward correlation chain (A>B>C>D) and chain reversion (D>C>B>A).

Table S1 Product-moment correlation matrix of variables in the original dataset. Values in bold font style have an association of p ≤ 0.05.

Variable	Age	Age@ 1st Child	Age@ Final Child	Men- strual periods	Height	Sitting height	Knee height	Weight	Arm	Waist	Triceps	Arm muscle area	Arm fat area	BMI	Educa- tion level	Age@ Mar- riage	Total preg- nancies	Total living chil- dren	Unsuc- cessful preg- nancies	Lag_ marry- birth1	SPPB total_ score
Age	1.00																				
Age@1stChild	**0.32**	1.00																			
Age@FinalChild	**0.69**	**0.45**	1.00																		
Menstrual periods	**-0.68**	-0.12	**-0.55**	1.00																	
Height	-0.11	0.13	-0.20	0.16	1.00																
Sitting height	-0.17	-0.04	-0.27	0.14	**0.74**	1.00															
Knee height	-0.10	0.23	-0.15	0.21	**0.80**	**0.38**	1.00														
Weight	**-0.33**	-0.13	**-0.35**	**0.40**	**0.41**	**0.52**	**0.31**	1.00													
Arm	-0.15	-0.11	-0.25	0.22	0.18	**0.32**	0.09	**0.88**	1.00												
Waist	-0.16	-0.15	-0.22	**0.27**	0.24	**0.40**	0.16	**0.92**	**0.87**	1.00											
Triceps	-0.25	-0.17	**-0.40**	**0.34**	0.08	**0.30**	0.01	**0.72**	**0.76**	**0.67**	1.00										
Arm muscle area	0.09	0.04	0.11	-0.08	0.18	0.13	0.12	**0.48**	**0.62**	**0.52**	-0.04	1.00									
Arm fat area	-0.22	-0.17	**-0.36**	**0.31**	0.13	**0.32**	0.05	**0.83**	**0.90**	**0.78**	**0.96**	0.23	1.00								
BMI	**-0.33**	-0.19	**-0.32**	**0.39**	0.11	**0.32**	0.08	**0.95**	**0.90**	**0.92**	**0.76**	**0.45**	**0.86**	1.00							
Education level	**-0.38**	0.21	**-0.36**	**0.44**	0.17	0.20	0.15	0.26	0.16	0.14	0.24	-0.07	0.21	0.22	1.00						
Age@Marriage	0.05	**0.39**	0.14	-0.04	0.03	0.05	0.00	-0.10	-0.17	-0.14	-0.16	-0.08	-0.19	-0.12	**0.22**	1.00					
Total pregnancies	**0.40**	-0.11	**0.41**	**-0.34**	-0.23	-0.26	-0.10	-0.16	-0.10	-0.01	-0.20	0.08	-0.16	-0.11	**-0.38**	**-0.38**	1.00				
Total living children	**0.30**	-0.24	**0.33**	**-0.36**	-0.21	-0.18	-0.11	-0.10	-0.00	0.06	-0.17	0.20	-0.10	-0.04	**-0.33**	**-0.35**	**0.86**	1.00			
Unsuccessful Preg nancies	**0.32**	0.11	**0.28**	-0.14	-0.09	-0.18	0.01	-0.13	-0.19	-0.06	-0.10	-0.16	-0.15	-0.12	-0.24	-0.20	**0.60**	0.12	1.00		
Lag_marry-birth1	**0.30**	**0.79**	**0.39**	-0.10	0.12	-0.08	**0.24**	-0.07	-0.01	-0.07	-0.07	0.10	-0.06	-0.12	0.08	-0.25	0.14	-0.02	0.25	1.00	
SPPB Total score	**-0.43**	0.06	-0.20	0.17	0.10	-0.13	**0.30**	-0.05	-0.14	-0.22	-0.16	-0.04	-0.14	-0.11	0.21	-0.11	-0.06	-0.02	-0.10	0.14	1.00