Growth curve models for weight among infants: a scoping review protocol

Martao Alves[1,2,3] • Sofia Serra[2,4] • Teresa Costa[2,4] • Carlos Brás-Geraldes[3,5] • Ana Luisa Papoila[1,2,3] • Bruno Heleno[2]

[1]Epidemiology and Statistics Unit, Research Center, Unidade Local de Saúde São José, Centro Clínico Académico de Lisboa, Lisbon, Portugal, [2]NOVA Medical School, Faculdade de Ciências Médicas da Universidade Nova de Lisboa (UNL), Lisbon, Portugal, [3]Centro de Estatística e Aplicações da Universidade de Lisboa (CEAUL), Lisbon, Portugal, [4]Centro de Estudos Clássicos, Faculdade de Letras, Universidade de Lisboa, Lisbon, Portugal, and [5]Instituto Superior de Engenharia de Lisboa (ISEL) do Instituto Politécnico de Lisboa, Lisbon, Portugal

ABSTRACT

Objective: This scoping review aims to provide a systematic overview of the literature on statistical models to estimate weight growth curves among infants, examining key features such as study design, sample size, and statistical approaches.

Introduction: Growth models were first developed to estimate individuals' growth curves by modeling each individual separately. Later, with the aim of estimating mean trajectories, approaches using mixed effects regression models were proposed. More flexible models were also applied in this context, enabling the estimation of more parameters (eg, Generalized Additive Models for Location, Scale, and Shape; SuperImposition by Translation and Rotation models).

Inclusion criteria: Studies of statistical/mathematical methodologies for estimating weight growth curves of infants under 24 months of age, based on prospective/retrospective cohorts, or cross-sectional studies will be included. Only studies published in English, Portuguese, or Spanish will be considered. Case series reports, reviews, short letter publications, books, and abstract-only papers, such as conference proceedings, will be excluded.

Methods: This review will be conducted in accordance with the JBI methodology for scoping reviews. The databases, PubMed, Scopus, Web of Science Core Collection, SciELO, and LILACS, will be searched for published studies, while ProQuest and RCAAP will be searched for unpublished studies. Search results will be imported into Rayyan to remove duplicates. Two reviewers will independently screen titles, abstracts, and full-text articles. Any disagreements will be resolved through discussion or with a third reviewer. The resulting data, namely mathematical/statistical approaches and models, will be summarized in tabular format, accompanied by a narrative summary.

Review registration: Open Science Framework https://osf.io/95udq

Keywords: growth curves; infants; scoping review; statistical models; weight

JBI Evid Synth 2024; 22(00):1–7.

Introduction

Human growth involves both gradual enlargement of the entire body or specific parts, and individual aging. Human physical growth is a complex phenomenon that depends on individual and environmental factors, such as nutritional status, genetics, socioeconomic status, the occurrence of diseases in childhood and adolescence, physical activity, geographic region, and climatic conditions.[1] Anthropometric measurements, including length or height, weight, waist circumference, and head circumference, are used to assess this growth. In children, assessing their growth is crucial to ensure it aligns with healthy development standards. The early years are marked by rapid growth, and therefore, regular assessments are essential for tracking a child's well-being and identifying any deviations from expected growth trajectories. These years are also critically important and highly sensitive to changes in

Correspondence: Marta Susana Ferreira Leitão Alves das Lages, marta.alves@ulssjose.min-saude.pt

The authors declare no conflicts of inetrest.

DOI: 10.11124/JBIES-24-00152

dietary habits.[2–5] Feeding recommendations vary across countries depending on the sociocultural characteristics of the population, and consequently, on breastfeeding practices. Growth patterns differ if we consider exclusively breastfed infants or formula-fed infants.[6,7] Moreover, cultural, ethnic, and gender differences exist in the growth pattern. For instance, regarding gender, boys tend to have a slightly higher birth weight than girls, although during infancy they follow similar growth trajectories. Nonetheless, the World Health Organization (WHO) recommends growth reference curves for infants separately by sex.

Growth curves are instrumental in assessing infant growth using various mathematical and statistical models, classified into non-structural (non-parametric) or structural (parametric) categories.[8] Non-structural models, which include fractional polynomials[9] and splines,[10] do not assume a specific shape for the growth curve, making them easy to fit. However, their major limitation is the parameters' lack of biological interpretability.[8] In contrast, structural models assume a basic functional form of the growth curve, often achieving a good fit with fewer parameters, thus allowing some biological interpretation.[11] Early parametric models were pioneered by Jenss-Bayley (1937),[12] using an exponential function; Count (1943),[13] employing a logarithmic approach; and Berkey and Reed (1987),[14] enhancing model fit by adding extra terms.

In the early 2000s, a novel approach was proposed using mixed effects regression models (that considers the autocorrelation structure between the longitudinal observations).[15,16] Several of the referred models were adapted to this new methodology. Effectively, any structural or non-structural model can be expressed using a mixed effects regression approach considering all children simultaneously rather than fitting them individually. Fixed effects represent the mean population growth curve, while the random effects allow the estimation of between-subject variability (individual variation around the mean population curve).[17]

In 2005, Rigby and Stasinopoulos[18] proposed a class of more flexible univariable statistical models—the Generalized Additive Models for Location, Scale, and Shape (GAMLSS)—that enable the modeling of the parameters that characterize the distribution of the response variable. In this human growth modeling context, the WHO Multicenter Growth Reference Study has developed growth standards describing the growth of healthy breastfed infants living in 6 countries from diverse geographical regions with socioeconomic conditions that are favorable for growth, assuming that breastfeeding is the biological norm for growth and development.[19] The model is based on the Box–Cox power-exponential distribution, with 4 parameters (location, scale, skewness, and kurtosis), developed by Rigby and Stasinopoulos.[20] This model was adopted for estimating the WHO children growth curves. This approach, where curve smoothing is obtained by using cubic splines, allows to model moments of the distribution as smooth curves in age. The WHO standards demonstrated for the first time, that when given an optimum start in life, children born in different regions of the world have the potential to grow to reach the same ranges of weight and height for their age.[19] These standards show how healthy breastfed children are supposed to grow, wherever they come from. Therefore, they can help health professionals and parents to check, by plotting a child's growth on the chart, whether growth and development are as expected. Moroever, this may help with the early identification and treatment of some growth disorders. These growth charts are also important tools in the definition of public health policies, mainly in lower-middle-income countries, to approximate their infant growth with the WHO standards.

Five years later, in 2010, Cole *et al.*[21] proposed the SuperImposition by Translation and Rotation (SITAR) semi-parametric model, an extension of the shape-invariant random effects model introduced by Beath.[22] SITAR became popular because it overcomes the problem of the lack of biological interpretation of the estimated parameters.[23] This model estimates an average growth curve for the study population using a natural cubic spline function. It also summarizes individual growth relative to the average trajectory through 3 key parameters: size, tempo, and velocity.[24] These parameters are seen as the deviation of an individual's growth trajectory from the average curve.[25]

A scoping review is appropriate for identifying and mapping the available evidence in a given field and analyzing knowledge gaps.[26] The various approaches to modeling infant growth described above indicate a fragmented field with diverse methods and outcomes. Therefore, it is necessary to map the statistical and mathematical approaches/models used for estimating growth curves for weight in infants under 24 months. This review will identify knowledge gaps, trace the evolution of the models, and examine the models used, including study design, sample size, and specific characteristics. By providing such a comprehensive review, the findings will be of major importance; they will be useful for developing models with higher performance, while weight estimates will be less biased and more precise. Accordingly, the information that health professionals and parents retrieve from the growth curves will be more accurate.

A preliminary search of MEDLINE, the Cochrane Database of Systematic Reviews, and *JBI Evidence Synthesis* was conducted and no current or in-progress scoping reviews or systematic reviews on the topic were identified. Only one systematic review was identified, but it offers recommendations about statistical models to be used for estimating linear growth velocity, not weight growth. Our purpose is to identify and map the available evidence about statistical/mathematical approaches to estimate growth curves for weight among infants under 24 months of age. The review will also identify knowledge gaps and establish the evolution of statistical growth models for weight over the years.

Review questions

What types of approaches/models are used for estimating weight growth curves among infants?

i) What are the strengths and weaknesses of the selected models?
ii) What are the knowledge gaps in the existing models?

Inclusion criteria

Participants

This review will consider studies on infants aged 0 to 24 months. This specific age range was chosen due to the importance of monitoring infant growth during this critical developmental phase.

Concept

This review will identify studies on growth curve estimation, focusing on the development of new models, the application of existing models, or both.

Context

This review will include studies from all populations, regardless of geographical location, cultural and ethnic background, breastfeeding practices, and socioeconomic status.

Types of sources

This scoping review will only consider studies with an epidemiological design suitable for this research subject. Accordingly, quantitative study designs (ie, observational studies such as prospective or retrospective cohort studies and cross-sectional studies) will be included. Conversely, qualitative studies, case series reports, reviews, short letter publications, books, and abstract-only papers such as conference proceedings, will be excluded.

Methods

The proposed review will be conducted in accordance with the JBI methodology for scoping reviews,[27] and in line with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR).[28]

Search strategy

The search strategy will aim to locate both published and unpublished studies. An initial limited search of PubMed was undertaken to identify articles on the topic. The text words contained in the titles and abstracts of relevant articles, and the index terms used to describe the articles, were used to develop a full search strategy for PubMed (see Appendix I). The design and refinement of the search strategy will be undertaken with consultation from an experienced librarian. The search strategy, including all identified keywords and index terms, will then be adapted for each included information source.

Only articles published in Portuguese, English, and Spanish will be included due to lack of translation resources. Articles published from database inception up to 2024 will be included in this review.

The databases to be searched will include PubMed, Scopus, Web of Science Core Collection, SciELO Citation Index, and LILACS. The search for unpublished studies will include ProQuest Dissertations and Theses Citation Index and RCAAP (Repositórios Científicos de Acesso Aberto de Portugal).

Study/Source of evidence selection

Following the search, the authors will screen all the identified records uploaded into Rayyan (Qatar Computing Research Institute, Doha, Qatar), where duplicates will be removed. The selection of articles for inclusion in the review will be conducted in 2 steps. In the first step, titles, keywords, and abstracts will be screened against the eligibility criteria. Abstracts not meeting all inclusion criteria will be excluded. The second step will involve full-text screening of papers that are potentially relevant after being retrieved and imported into Rayyan. Eligibility assessment will be undertaken in duplicate by 2 reviewers working independently. Additionally, to locate articles not identified during the database search process, the references of the included articles will be reviewed. The titles that suggest a relationship with the topic will be selected and entered into Rayyan for screening according to the steps above. Articles that meet the inclusion criteria will be added to the existing list of previously included articles. Reasons for exclusion of full-text papers that do not meet the inclusion criteria will be recorded and reported in the scoping review. Any disagreements that arise between the 2 reviewers in the first step of the selection process will be resolved through discussion, while in the second step, the final decision will be made by a third reviewer. The results of the search will be reported in full in the final scoping review and presented in a PRISMA flow diagram.[29]

Data extraction

Data will be extracted by 2 independent reviewers using a data extraction tool developed by the reviewers based on the JBI template. The extracted data will include specific details about author(s), year of article publication, country, aims/purpose, study design, sample size, age range, statistical/mathematical approaches, and key findings relevant to the review question. A draft extraction tool is provided in Appendix II. The tool will be piloted on 3 potentially eligible studies and modified and revised if needed. Further refinements to the extraction tool may be made during the process of extracting data from each paper. Modifications will be detailed in the full scoping review. Any disagreements that arise between the reviewers will be resolved through discussion. The corresponding authors of papers will be contacted up to 3 times to request missing or additional data.

Data analysis and presentation

A descriptive analysis of the findings will be conducted and presented in tabular format, followed by a comprehensive narrative approach describing how the results relate to the review question. Studies will be organized according to their approach (statistical or mathematical) and class (structural or non-structural). No quantitative analyses using the selected papers will be performed. If knowledge gaps are found, they will also be described in tabular format, as well as strengths and weaknesses of the identified models. Many of these positive and negative aspects of the models that are commonly used to analyze weight data are known a priori (e.g. biological interpretability of the results, ease of fitting, flexibility, complexity, ease of implementation, ability to model complex distributions, and ability to cope with missing data). For less used models, a comprehensive and detailed reading of the papers will be required to analyze them regarding the previous aspects. However, if some of these papers are exclusively about applications to specific weight data without referring to the model's details, the lacking information will be obtained in the corresponding theoretical papers.

Acknowledgments

This scoping review forms part of a PhD for MA.

Author contributions

MA conceptualized the review. All authors (MA, SL, TC, CG, ALP, BH) were involved in the drafting, revision, and completion of the review.

References

1. Bamba V, Kelly A. Assessment of growth. In: Kliegman RM, St Geme III JW, editors. Nelson Textbook of Pediatrics, 21st ed. Elsevier; 2020.
2. Hauspie RC, Vercauteren M, Susanne C. Secular changes in growth. Horm Res 1996;45(2):8–17.
3. Tanner JM. Foetus into man: physical growth from conception to maturity. Harvard University Press; 1990.
4. Yang M, Leung SS. A comparison of the growth patterns of Chinese infants in Chengdu and Hong Kong: 0-2 years. J Paediatr Child Health 1994;30(4):336–40.
5. Vahabi N, Kazemnejad A, Fallah R. Length and weight growth trends for children less than two years old in Zanjan, Iran: longitudinal modeling. Med J Islam Repub Iran 2016;30:374.
6. de Onis M, Garza C, Onyango AW, Rolland-Cachera MF, Le Comité de Nutrition de la Société Française de Pédiatrie. Les standards de croissance de l'Organisation Mondiale de la Santé pour les nourrissons et les jeunes enfants. [WHO

growth standards for infants and young children]. Arch Pediatr 2009;16(1):47–53; French.
7. WHO Working Group on Infant Growth. An evaluation of infant growth: the use and interpretation of anthropometry in infants. Bull World Health Organ 1995;73(2):165–74.
8. Hauspie R, Molinari L. Parametric models for postnatal growth. In: Hauspie R, Cameron N, Molinari L, editors. Methods in human growth research. Cambridge University Press; 2004.
9. Wen X, Kleinman K, Gillman MW, Rifas-Shiman SL, Taveras EM. Childhood body mass index trajectories: modeling, characterizing, pairwise correlations and socio-demographic predictors of trajectory characteristics. BMC Med Res Methodol 2012;12:38.
10. Tilling K, Davies NM, Nicoli E, Ben-Shlomo Y, Kramer MS, Patel R, *et al*. Associations of growth trajectories in infancy and early childhood with later childhood outcomes. Am J Clin Nutr 2011;94(6):1808S–813SS.
11. Beath KJ. Infant growth modelling and assessment of growth. In: Preedy V, editor. Handbook of growth and growth monitoring in health and disease. Springer; 2012.
12. Jenss RM, Bayley N. A mathematical method for studying the growth of a child. Hum Biol 1937;9(4):556–63.
13. Count EW. Growth patterns of the human physique: an approach to kinetic anthropometry: Part I. Hum Biol 1943; 15(1):1–32.
14. Berkey CS, Reed RB. A model for describing normal and abnormal growth in early childhood. Hum Biol 1987; 59(6):973–87.
15. Pinheiro JC, Bates DM. Mixed-effects models in s and s-plus. Springer; 2000.
16. Fitzmaurice GM, Laird NM, Ware JH. Applied longitudinal analysis. Wiley; 2012.
17. Regnault N, Gillman MW, Kleinman K, Rifas-Shiman S, Botton J. Comparative study of four growth models applied to weight and height growth data in a cohort of US children from birth to 9 years. Ann Nutr Metab 2014;65(2-3):167–74.
18. Rigby RA, Stasinopoulos DM. Generalized additive models for location, scale and shape. Appl Statist 2005;54(3):507–54.
19. World Health Organization Multicentre Growth Reference Study Group. WHO child growth standards: length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for-age: methods and development [internet]. WHO; 2006 [cited 2024 Mar 10]. Available from: https://www.who.int/childgrowth/standards/technical_report/en/.
20. Rigby RA, Stasinopoulos DM. Smooth centile curves for skew and kurtotic data modelled using the Box-Cox power exponential distribution. Stat Med 2004;23:3053–76.
21. Cole TJ, Donaldson MD, Ben-Shlomo Y. SITAR–a useful instrument for growth curve analysis. Int J Epidemiol 2010;39:1558–66.
22. Beath KJ. Infant growth modelling using a shape invariant model with random effects. Stat Med 2007;26(12):2547–64.
23. Johnson W. Analytical strategies in human growth research. Am J Hum Biol 2015;27(1):69–83.
24. Regnault N, Gillman MW. Importance of characterizing growth trajectories. Ann Nutr Metab 2014;65(2-3):110–3.
25. Woo JG, Sucharew H, Su W, Khoury PR, Daniels SR, Kalkwarf HJ. Infant weight and length growth trajectories modeled using Superimposition by Translation and Rotation are differentially associated with body composition components at 3 and 7 years of age. J Pediatr 2018;196:182–88.e1.
26. Munn Z, Peters MDJ, Stern C, Tufanaru C, McArthur A, Aromataris E. Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. BMC Med Res Methodol 2018;18(1):143.
27. Peters MDJ, Godfrey C, McInerney P, Munn Z, Tricco AC, Khalil H Chapter 11: Scoping reviews. In: Aromataris E, Munn Z, editors. JBI Manual for Evidence Synthesis [internet]. JBI; 2020 [cited 2024 Mar 27]. Available from: https://jbi-global-wiki.refined.site/space/MANUAL/355863557/Previous+versions?attachment=/download/attachments/355599504/JBIMES_2021April.pdf&type=application/pdf&filename=JBIMES_2021April.pdf.
28. Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, *et al*. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. Ann Intern Med 2018;169(7):467–73.
29. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, *et al*. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71.

Appendix I: Search strategy

PubMed

Search conducted on July 25, 2024.

Search	Query	Records retrieved
#1	"Growth Chart*"[All fields] OR "centile curve*"[All fields] OR "child growth curve*"[All fields] OR "childhood growth"[All fields] OR "Growth Curve*"[All fields] OR "growth curve estimates"[All fields] OR "growth trajector*"[All fields] OR "infant growth curve estimates"[All fields] OR "reference centile curves"[All fields] OR "WHO growth standard curve*"[All fields]	20,831
#2	Body Weight[MeSH Terms] OR Body-Weight Trajectory[MeSH Terms] OR weight[All fields] OR "weight data"[All fields] OR "weight growth"[All fields] OR "weight trajector*"[All fields] OR "weight velocity curve*"[All fields] OR weight-for-age [All fields] OR weight-for-length[All fields] OR "growth in weight"[All fields] OR "longitudinal weight"[All fields]	1,903,787
#3	Models, Statistical[MeSH Terms] OR "growth model*"[All fields] OR "longitudinal child growth model*"[All fields] OR "Mathematical growth model*"[All fields] OR "mathematical model*"[All fields] OR "statistical model*"[All fields] OR "Growth curve model*"[All fields] OR model*[All fields]	4,949,477
#4	#1 AND #2 AND #3	2263
#5	#1 AND #2 AND #3 NOT ("fetale"[All Fields] OR "fetals"[All Fields] OR "fetus"[MeSH Terms] OR "fetus"[All Fields] OR "fetal"[All Fields] OR "foetal"[All Fields])	1854
#6	Limit 5 to (Humans)	1310
#7	Limit 5 to (Humans) and (Infant: birth-23 months)	551

Appendix II: Data extraction instrument

Scoping review title	
Author(s)	
Journal	
Year of publication	
Country	
Aims/purpose	
Study design	
Sample size	
Age range	
Statistical/Mathematical approaches	