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ORIGINAL ARTICLE

New French height velocity growth charts: An innovative big-data approach based on routine measurements

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Abstract

Aim: Height velocity is considered a key auxological tool to monitor growth, but updated height velocity growth charts are lacking. We aimed to derive new French height velocity growth charts by using a big-data approach based on routine measurements.

Methods: We extracted all growth data of children aged 1 month–18 years from the electronic medical records of 42 primary care physicians, between 1 January 1990 and 8 February 2018, throughout the French metropolitan territory. We derived annual and biannual height velocity growth charts until age 15 years by using the Lambda-Mu-Sigma method. These new growth charts were compared to the 1979 French and 2009 World Health Organisation (WHO) ones.

Results: New height velocity growth charts were generated with 193 124 and 209 221 annual and biannual values from 80 204 and 87 260 children, respectively, and showed good internal fit. Median curves were close to the 1979 French or 2009 WHO ones,

Abbreviations: PCP, Primary care physician; SD, Standard deviation.; WHO, World Health Organisation.

but SD curves displayed important differences. Similar results were found with the biannual height velocity growth charts.

Conclusion: We produced new height velocity growth charts until age 15 years by using a big-data approach applied to measurements routinely collected in clinical practice. These updated growth charts could help optimise growth-monitoring performance.

KEYWORDS
big-data, child, models, velocity height growth chart

1 | INTRODUCTION

Accurate growth monitoring offers the potential for early detection of numerous serious health conditions such as growth hormone deficiency, Turner syndrome and craniopharyngioma in order to improve their prognosis. Growth monitoring is also pivotal to precisely monitor the effect of different treatments on auxological parameters, notably height velocity, and/or to study growth determinants in the general population.[1] Height monitoring relies on growth charts and the use of several auxological parameters. [1] Static parameters include standardised height or distance to standardised target height, and dynamic ones include changes in standard deviation (SD) score for height or height velocity.[2] Dynamic parameters are widely recommended for the early detection of severe conditions, and height velocity is one of the most sensitive criteria for the early detection of abnormal growth.[3–6] Because the tempo of growth and puberty have secularly changed in many countries, maintaining updated height velocity growth charts is pivotal for the overall performance of growth monitoring, but it is also a challenge because the derivation of height velocity growth charts requires the availability of a large number of height measurements at 6- or 12-month precise intervals.

Currently, several growth charts for height velocity are available. They vary in the population involved (country, recruitment, year of inclusion) and the methodological choices in their construction (e.g., sample size, age interval, data collection protocols and statistical approaches) (Table S1).[7–26] In many countries, available height velocity growth charts were derived from small samples that were not representative of the target population and/or were produced several decades ago although the tempo of growth has secularly changed.[27] In France, the previous height velocity growth charts, elaborated by Sempé et al. in 1979 and usually used, were constructed from data for 588 children born in the Paris region from 1953 to 1954 and followed up longitudinally until the end of growth, with strong attrition ($n = 171$ at age 18 years).[9] In 2009, height velocity growth charts were proposed by the World Health Organisation (WHO) and relied on a large and recent international sample of children with growth data collected at key ages to allow for calculating height velocity.[28] However, these height velocity growth charts were built for up to age 2 years only, whereas growth monitoring is still crucial far beyond this age. At the international level, there are currently no height velocity growth charts derived from a large and recent population-based longitudinal sample up to adolescence.[2]

Key notes

- Height velocity is considered a key auxological tool to monitor growth and to detect numerous serious health conditions early, but updated height velocity growth charts are lacking.
- Annual and biannual French height velocity growth charts until age 15 years were produced with an innovative big-data approach based on measurements routinely collected in clinical practice.
- Updated height velocity growth charts produced could help optimise growth-monitoring performance.

An innovative big-data approach applied to measurements routinely collected in clinical practice in primary care settings was recently introduced to easily update height, weight and head circumference growth charts.[29,30] Whether such an approach would allow for deriving height velocity growth charts is unknown given the requirement of a large number of height measurements at 6- or 12-month intervals. Indeed, routinely collected height measurements are not scheduled to respect such precise intervals. Thus, we aimed to derive for the first time new height velocity growth charts by using a big-data approach involving height measurements collected from routine clinical records.

2 | POPULATION AND METHODS

2.1 | Design and participants

We used a two-step multicentre longitudinal design. We randomly sampled 32 primary care paediatricians belonging to the French Association of Ambulatory Paediatrics after stratification by geographical area and size of urban area and 10 volunteer general practitioners belonging to the French Society of General Medicine from across the French metropolitan territory. The geographical repartition of primary care physicians (PCPs) was detailed in previous publications.[29,30] Auxological data for individual paediatric patients were extracted from electronic medical records completed by PCPs using the software commercialised by CompuGroup Medical Solutions. We initially included all children who were born after 1 January 1990 and aged 1 month–18 years by 8 February 2018 with a birth weight greater than 2500 g and who were measured at least once by a participating PCP. The overall methodology was described in detail elsewhere for the derivation of height, weight and head circumference growth charts.[29,30]

The study protocol was approved by the ethics committee and the institutional review board of the French Institute of Medical Research and Health (Inserm IRB00003888, IOR0003254, FWA00005831), which provided a waiver of consent given the completely anonymous design of data collection.

2.2 | Data collection and cleaning process

Participating PCPs had routinely entered data including sex, year of birth, height and age at growth measurement into the electronic medical records between 1990 and 2018. Data were automatically extracted from their computers from September 2017 to February 2018 and were anonymised and aggregated in a dedicated medical observatory for auxology. Children with an excessive number of measurements after age 6 months (see definition in Table S2) were excluded because frequent medical visits after this age were likely to reflect an underlying condition that might affect growth.[29,30] An automated process of cleaning was developed and applied to height data for detecting and deleting measurement or transcription errors. After removing duplicates, we deleted extreme absolute height z-scores (≥5 SD) and absolute height z-score variations between two successive measurements as detailed in Figure S1.[29,30]

2.3 | Derivation of new height velocity growth charts

We derived annual height velocity growth charts for ages 13 months–18 years. For each child, we looked for all height measurements for which another one was available 12 months earlier. We allowed departures from this 12-month interval of ±5 days before 1 year, ±7 days between 1 and 2 years, and ±15 days after 2 years (Figure 1), as suggested.[9,20,28] Annual height velocity was then calculated as the difference between the two height measurements. An additional data-cleaning process was then applied to delete measurement or transcription errors or a pathological process that resulted in negative or null annual height velocity values (n = 449/177 222 height velocity values) and/or absolute height velocity z-scores ≥4 SD (n = 986/176 773) (Figure S1). No interpolation was made during the entire process.

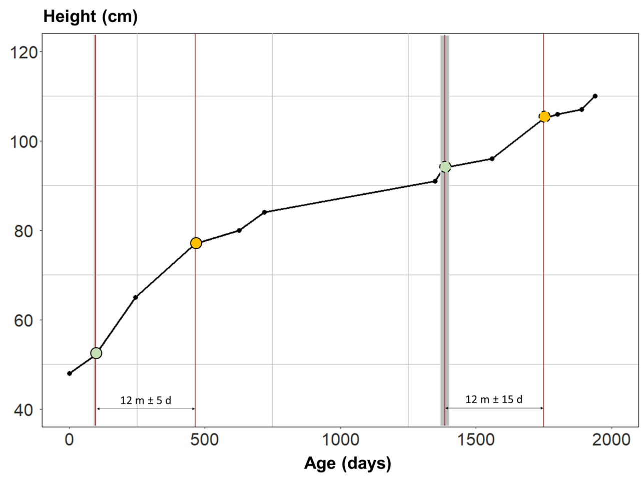


FIGURE 1 Principles for calculating the annual height velocity value for a given child. Among the 15 height measurements available for this healthy child between birth and age 5–6 years, only two (illustrated in non-dotted and dotted yellow circles, respectively, at 465 and 1795 days) had a height measurement available approximately 12 months earlier (illustrated in non-dotted and dotted green circles). Thus, this child only contributed to the annual height velocity growth charts with two height velocity values at 465 and 1795 days.

To check for a selection bias between the sub-sample of children used for deriving annual and biannual height velocity growth charts and the initial population used for generating the new height growth charts,[29] we calculated the mean (standard error) of the height z-score-for-age (in SD) of children included in the sub-sample based on the previously derived new height growth charts,[29] separately for girls and boys.

Using the individual annual height velocity values obtained at the previous step, we modelled their evolution in terms of age (in days) from age 13 months–18 years, separately for girls and boys, by using the Lambda-Mu-Sigma method within generalised additive models for location, scale and shape,[31,32] as already used in previous studies (Table S1).[18,20–22,24,25] The modelling of height velocity growth charts was based on the modelling of three distribution parameters according to age: the median, the coefficient of variation and the skewness. Cubic-penalised B-splines were used as smoothing functions, and the numbers of knots and equivalent degrees of freedom were determined for these three parameters. We obtained the best final model with a step-by-step process from the simplest to the most complicated and final one (Table S3). The best model was selected on the basis of the Generalised Akaike Information Criterion. The fit of the final model was internally checked by comparing the empirical SD curves to modelled SD curves and by inspecting the worm plots.[33] The process of modelling growth curves was described in more detail in previous publications.[29,30]

We also derived biannual (i.e., 6-month interval) height velocity growth charts for ages 7 months–18 years. For each child, we looked for all height measurements for which another one was available 6 months earlier and following the same protocol.

We had to truncate the height velocity annual and biannual growth charts at age 15 years given the paucity of height velocity values calculable after this age (<1500 values for both sexes).

2.4 | Comparison with previous growth charts

We graphically compared the new height velocity growth charts to the 1979 French and 2009 WHO height velocity ones by superimposing the median and ± 2 SD curves, separately for girls and boys. We also studied the position of the 1979 French or 2009 WHO height velocity growth charts by converting their median and ± 2 SD values to z-scores based on the new height velocity growth charts and graphically represented their z-score curves (in SD) according to age.

3 | RESULTS

There were 80 204 children with at least one of the 193 124 annual height velocity values available (Figure S2). The number of annual height velocity values calculable declined with age, from 68 544 for the 13- to 24-month range to 1402 for the 14- to 15-year range (Table S4). There were 87 260 children with at least one of 209 221 biannual height velocity values available (Figure S2). The number of biannual height velocity values calculable declined with age from 51 035 for the 7- to 13-month range to 805 for the 14- to 15-year range (Table S4). The median [interquartile range] (min-max) annual and biannual height velocity values calculable per child were 2 [1–3] (1–20) and 2 [1–3] (1–21), respectively (Figure S3). Among the children included in the sub-sample used for deriving the annual and biannual height velocity growth charts, the mean (standard error) of the height z-score-for-age based on the previously derived new height growth charts was 0.002 (0.996) and 0.003 (1.000) for girls and 0.008 (0.992) and 0.007 (0.996) for boys.

The annual and biannual height velocity growth charts modelled on the basis of these values are in Figure 2 and Figure S4, respectively (Tables 1 and 2). The distribution of the coefficient of variation and skewness according to age for the annual and biannual height velocity growth charts are in Figures S5 and S6. When comparing empirical SD curves with the modelled SD curves, few differences were observed, which suggested good internal fit. Inspection of worm plots also suggested good internal fit (Figures S7 and S8).

For the annual height velocity growth charts, median curves modelled in boys and girls were close to the 1979 French height velocity growth charts (Figure 3), as illustrated by the evolution with age of the z-score of median curves for the 1979 French height velocity growth charts based on the new ones: −0.06 SD on average for girls and −0.13 SD for boys (Figure 4). The most important differences in median curves were observed during the pubertal period, with a peak in height velocity occurring earlier on the new charts (approximately 6 months earlier for girls and 4 months earlier for boys). The −2 SD curves for the 1979 French height velocity growth charts were positioned above the new ones: −1.73 SD on average for girls and −1.63 SD for boys (Figure 3, Figure 4). The +2 SD curves for the 1979 French height velocity growth charts were positioned below the new ones: +1.44 SD on average for girls and + 1.20 SD for boys (Figure 3, Figure 4).

For the biannual height velocity growth charts, median modelled curves were also close to the 1979 French height velocity growth charts (Figure S9). The z-score of median curves for the 1979 French height velocity growth charts based on the new ones was positioned at −0.05 SD on average for girls and −0.09 SD for boys (Figure S10). The −2 SD curves for the 1979 French height velocity growth charts based on the new ones were positioned at −1.41 SD on average for girls and −1.44 SD for boys, whereas the +2 SD curves were positioned at +1.18 SD on average for girls and + 1.07 SD for boys (Figure S10). The most pronounced differences in SD curves were observed during the first months of life and the pubertal period. During these two periods, the SD curves based on the new growth charts were higher than those of the 1979 French ones.

For the biannual height velocity growth charts, median modelled curves were close to the 2009 WHO height velocity growth charts for the first 2 years of age, except for the first 6 months (−0.09 SD on average for girls and −0.11 SD for boys) (Figures S11 and S12). Differences in SD curves were also observed: the −2 SD and + 2 SD curves for the 2009 WHO height velocity growth charts based on the new ones were positioned at −1.68 SD and + 1.59 SD on average for girls and −1.75 SD and + 1.52 SD for boys, respectively (Figure S12).

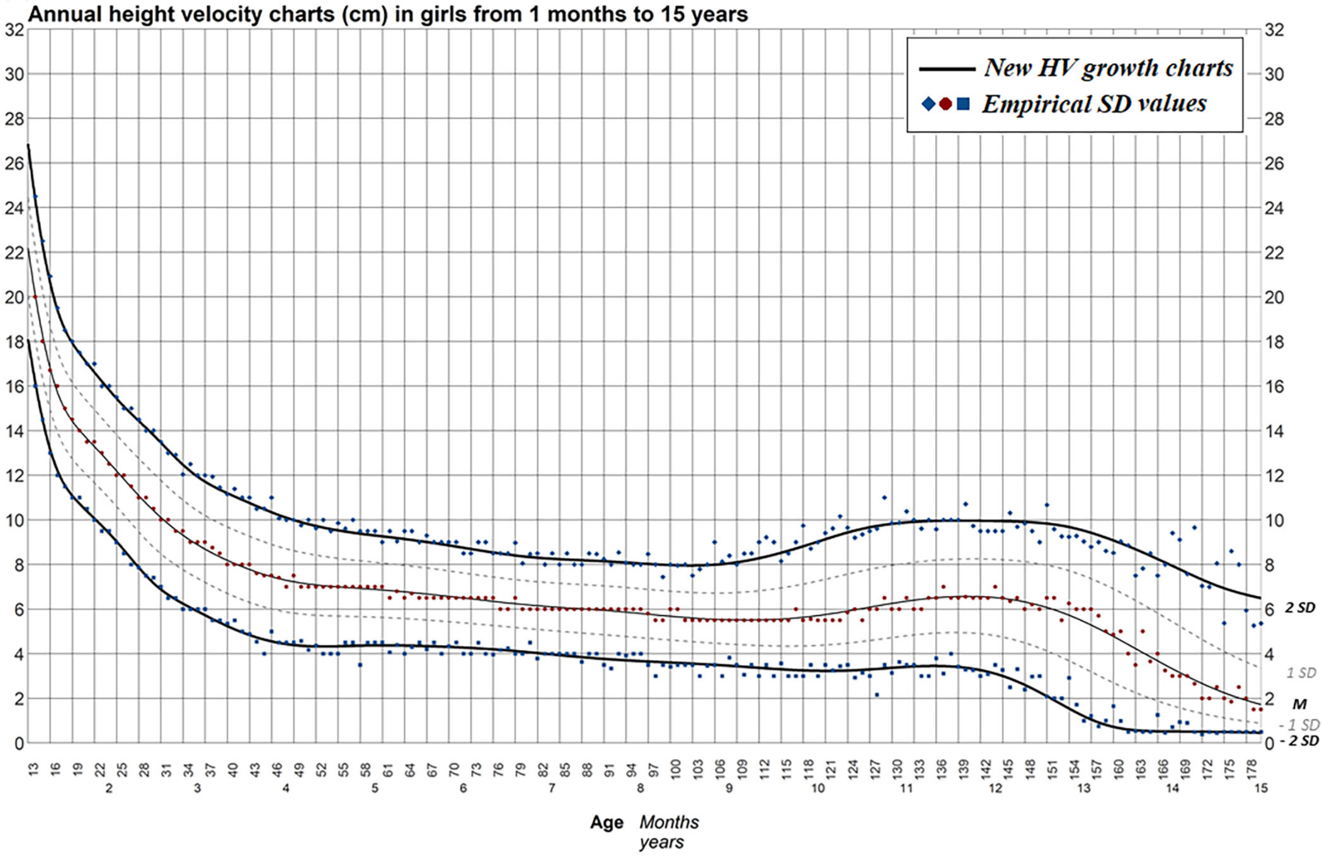
4 | DISCUSSION

4.1 | Main findings and interpretation

From height data routinely collected in clinical practice in primary care settings, we were able to produce up-to-date national annual and biannual height velocity growth charts until age 15 years. The median height velocity charts relying on contemporary children living in France were close to the 1979 French and 2009 WHO height velocity growth charts, although differences in growth tempo were observed during the puberty period. This difference has been reported in previous studies, suggesting a positive secular trend related to changes in environmental, nutritional or socioeconomic factors (notably the obesity epidemic) to which children are exposed very early in life.[34–39] Furthermore, we observed a similar median height velocity at age 15 years between the new and 1979 French height velocity growth charts, a finding potentially related to an earlier, longer and/or lower intensity of height velocity peak.[34,40] This finding has also been previously reported in studies from France and other countries.[34,41,42]

The new and the 1979 French height velocity growth charts showed differences in SD curves: the −2 and + 2 SD curves for the 1979 French height velocity growth charts were positioned between |1.07| and |1.73| SD on the new height velocity ones. Two

(A)


Annual height velocity charts (cm) in girls from 1 months to 15 years
New HV growth charts
Empirical SD values
2 SD
1 SD
M
- 1 SD
- 2 SD
Age Months
years

(B)

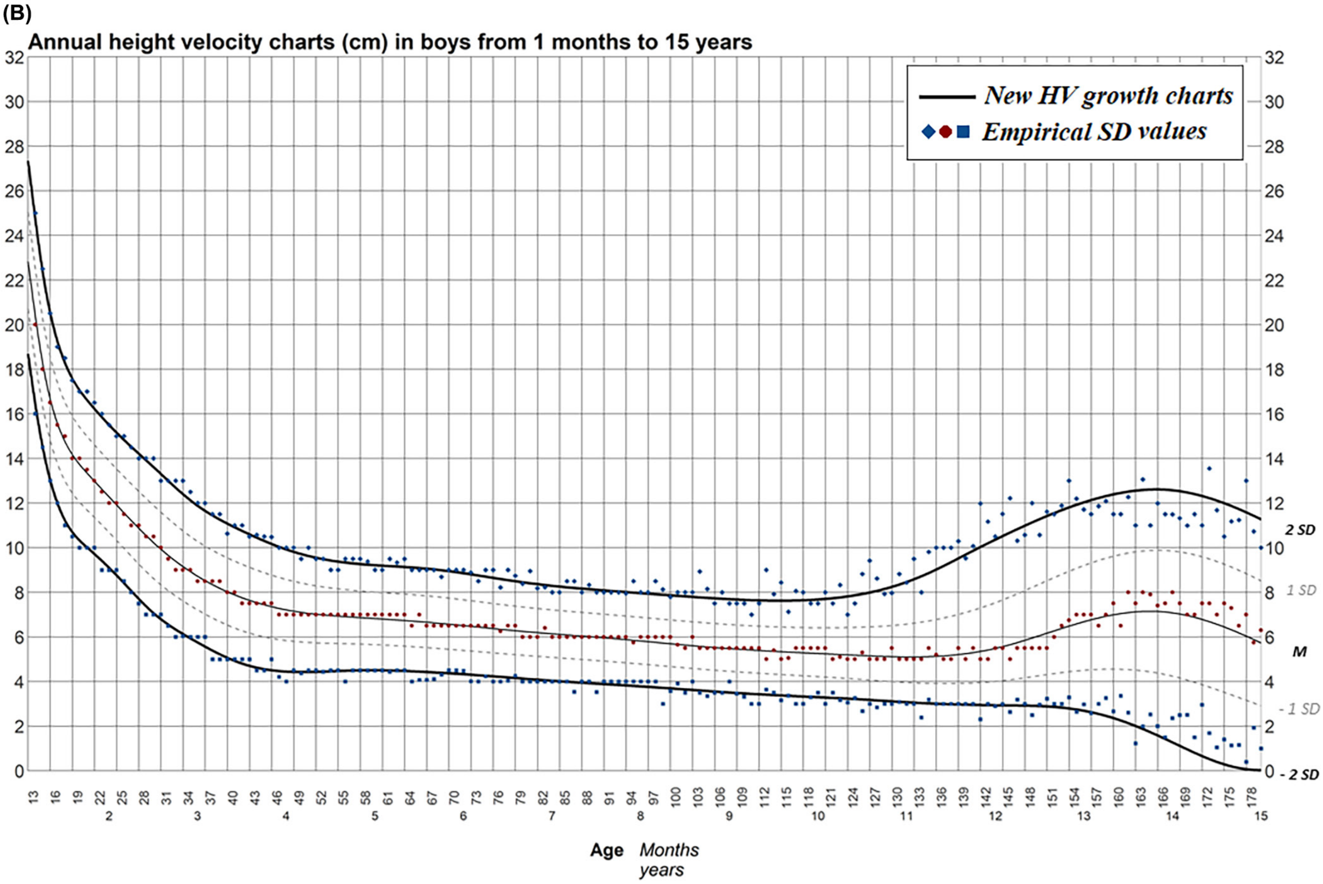

Annual height velocity charts (cm) in boys from 1 months to 15 years
New HV growth charts
Empirical SD values
2 SD
1 SD
M
- 1 SD
- 2 SD
Age Months
years

FIGURE 2 Annual height velocity growth charts compared to monthly empirical standard deviation (SD) values for girls (A) and boys (B), from age 13 months to 15 years.

TABLE 1 Reference values for annual height velocity growth charts for girls and boys.

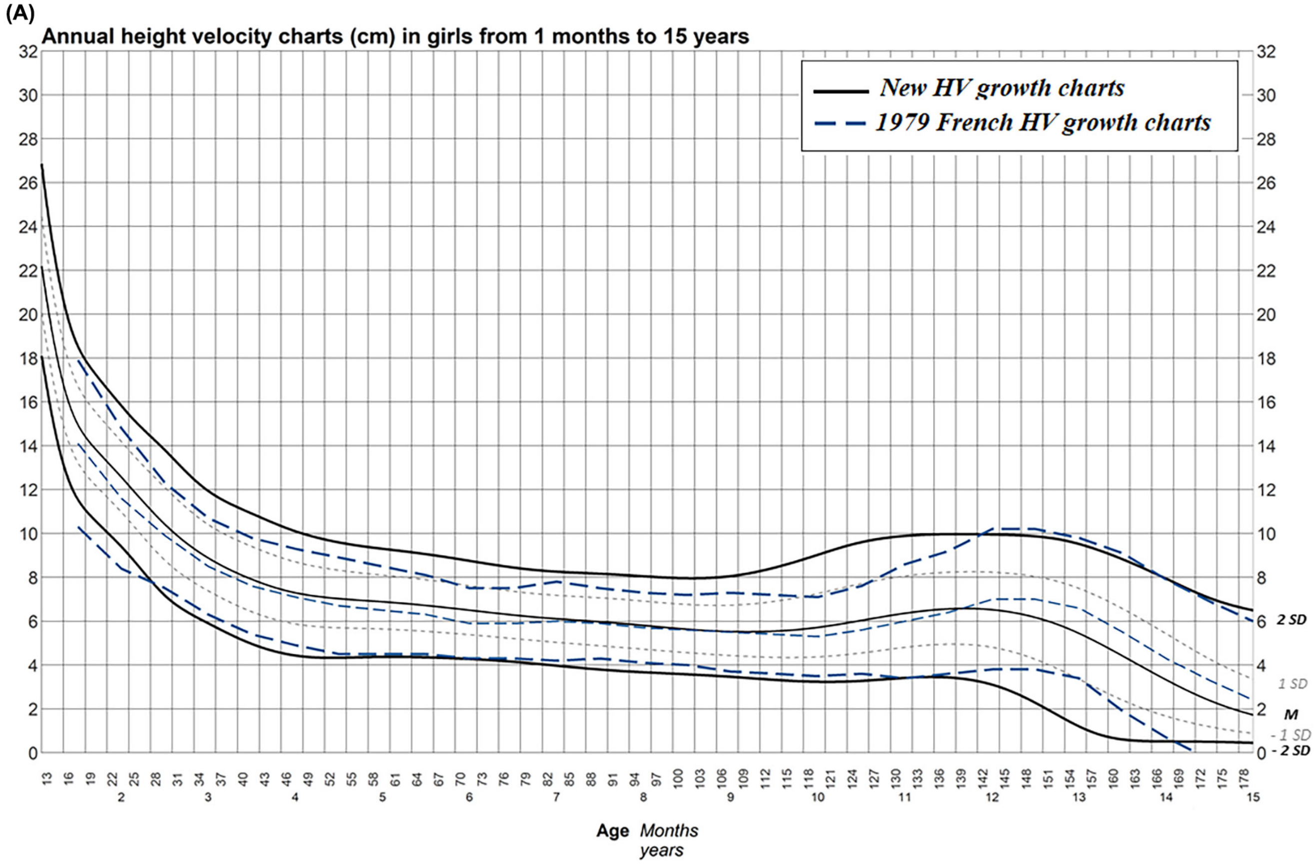
	Girls							Boys						
Age, months	L	S	-2 SD	-1 SD	Median	1 SD	2 SD	L	S	-2 SD	-1 SD	Median	1 SD	2 SD
13	0.4	0.1	17.9	19.9	22.0	24.3	26.6	0.4	0.1	18.4	20.4	22.5	24.8	27.2
24	0.9	0.1	9.4	11.0	12.6	14.2	15.8	0.9	0.1	9.1	10.7	12.3	13.9	15.6
36	0.8	0.2	5.9	7.4	8.9	10.5	12.1	0.8	0.2	5.8	7.2	8.7	10.3	11.9
48	0.9	0.2	4.4	5.8	7.2	8.7	10.2	1.0	0.2	4.4	5.8	7.2	8.6	10.0
60	1.0	0.2	4.3	5.6	6.9	8.2	9.4	0.8	0.2	4.4	5.6	6.8	8.0	9.3
72	1.0	0.2	4.2	5.3	6.5	7.6	8.8	0.7	0.2	4.2	5.3	6.5	7.7	9.0
84	0.9	0.2	3.9	5.0	6.1	7.3	8.4	0.8	0.2	4.0	5.0	6.1	7.3	8.4
96	0.8	0.2	3.6	4.7	5.8	7.0	8.2	0.8	0.2	3.7	4.7	5.8	6.9	8.0
108	0.7	0.2	3.2	4.3	5.5	6.8	8.2	0.7	0.2	3.4	4.4	5.5	6.6	7.8
120	0.7	0.3	3.1	4.4	5.8	7.3	8.9	0.4	0.2	3.2	4.1	5.2	6.5	7.9
132	0.7	0.3	3.4	4.8	6.4	8.0	9.8	0.2	0.3	2.9	3.9	5.1	6.6	8.5
144	0.7	0.3	3.1	4.7	6.4	8.3	10.3	0.2	0.3	2.9	4.1	5.6	7.6	10.2
156	0.7	0.4	1.7	3.4	5.3	7.6	10.1	0.4	0.4	2.8	4.5	6.7	9.3	12.5
168	0.5	0.6	0.7	1.8	3.4	5.5	8.1	0.7	0.4	2.0	4.2	6.9	10.0	13.4
180	0.3	0.7	0.4	0.9	1.8	3.3	5.5	0.8	0.5	0.8	3.0	5.7	8.5	11.6

TABLE 2 Reference values for biannual height velocity growth charts for girls and boys.

	Girls							Boys						
Age, months	L	S	-2 SD	-1 SD	Median	1 SD	2 SD	L	S	-2 SD	-1 SD	Median	1 SD	2 SD
7	0.6	0.1	11.2	12.8	14.4	16.2	18.0	0.5	0.1	12.0	13.5	15.2	17.0	18.9
12	0.8	0.2	5.6	6.9	8.2	9.6	11.0	0.9	0.2	5.4	6.7	8.1	9.5	10.9
24	1.0	0.2	3.0	4.4	5.7	7.1	8.5	1.0	0.2	2.9	4.3	5.6	7.0	8.3
36	1.0	0.3	1.8	3.0	4.2	5.4	6.6	1.0	0.3	1.7	2.9	4.1	5.3	6.5
48	0.9	0.3	1.4	2.5	3.6	4.7	5.8	0.9	0.3	1.4	2.4	3.5	4.6	5.7
60	0.9	0.3	1.4	2.4	3.4	4.4	5.5	0.9	0.3	1.4	2.4	3.4	4.4	5.5
72	0.8	0.3	1.4	2.3	3.2	4.2	5.2	0.8	0.3	1.4	2.3	3.2	4.1	5.2
84	0.8	0.3	1.3	2.1	3.0	3.9	4.9	0.8	0.3	1.4	2.2	3.0	4.0	5.0
96	0.8	0.3	1.2	2.0	2.9	3.8	4.7	0.7	0.3	1.2	2.0	2.8	3.8	4.7
108	0.8	0.3	1.1	1.9	2.8	3.8	4.8	0.7	0.3	1.1	1.9	2.7	3.7	4.7
120	0.8	0.4	1.0	2.0	3.0	4.1	5.3	0.7	0.4	1.0	1.7	2.6	3.6	4.7
132	0.7	0.4	1.0	2.0	3.2	4.5	6.0	0.6	0.4	0.9	1.7	2.6	3.7	4.9
144	0.6	0.4	0.9	1.8	3.0	4.5	6.2	0.6	0.4	0.9	1.8	2.9	4.3	5.8
156	0.5	0.5	0.7	1.4	2.4	3.8	5.4	0.6	0.5	1.0	2.0	3.4	5.1	7.1
168	0.3	0.5	0.4	0.9	1.7	2.8	4.3	0.5	0.5	0.8	1.9	3.3	5.1	7.4
180	0.2	0.6	0.3	0.6	1.1	2.0	3.4	0.5	0.5	0.6	1.5	2.7	4.4	6.5

main hypotheses could explain these differences. First, they could reflect a real variability in growth higher in contemporary children than in those born in the 1960s. The environment to which children are exposed today and their lifestyle has greatly changed over these decades but may also have become more variable between individuals.[43] Second, the children whose height measurements were used to generate the 1979 French height velocity growth charts were from a homogeneous population of children living in only one region

(A)


Annual height velocity charts (cm) in girls from 1 months to 15 years
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- 1 SD
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Age Months
years

(B)

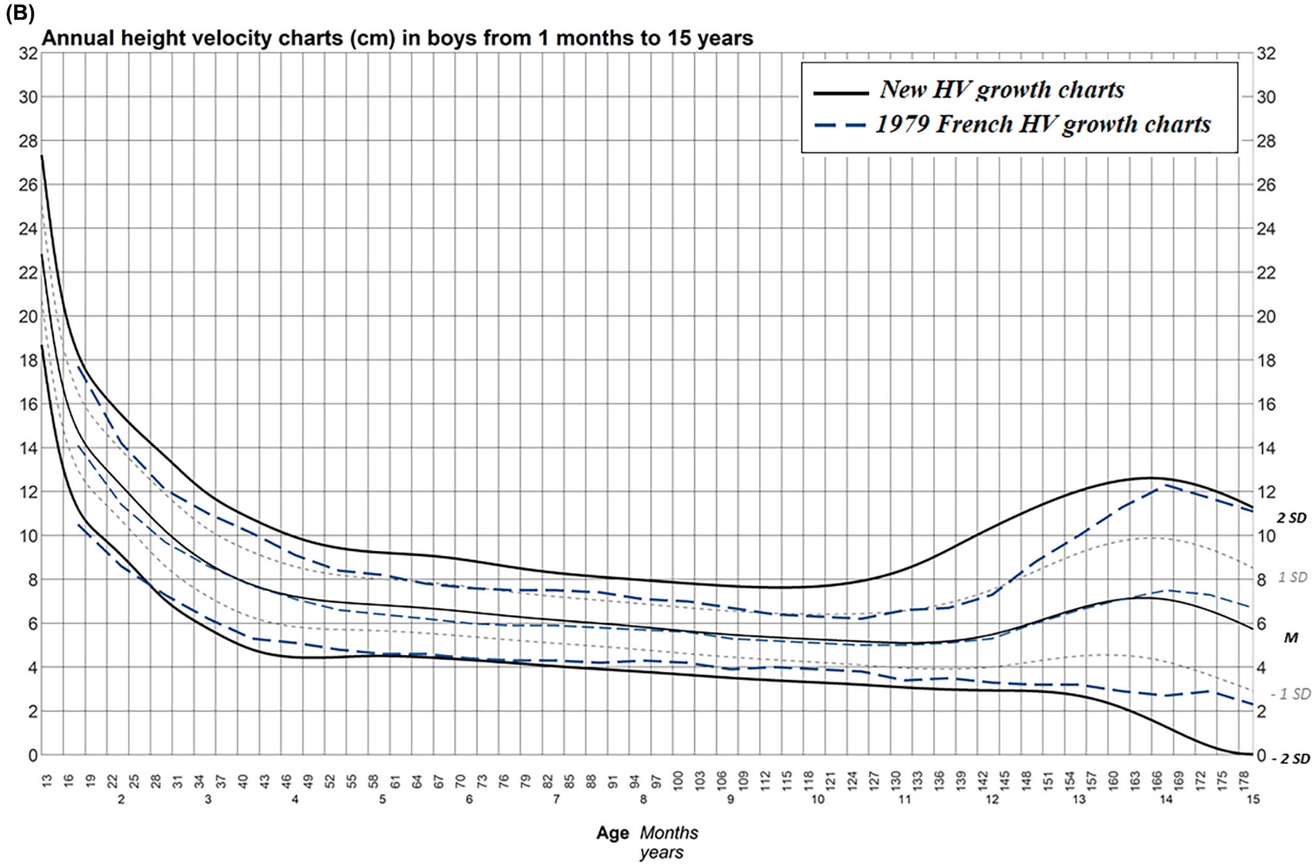

Annual height velocity charts (cm) in boys from 1 months to 15 years
New HV growth charts
1979 French HV growth charts
2 SD
1 SD
M
- 1 SD
- 2 SD
Age Months
years

FIGURE 3 Annual height velocity growth charts compared to the 1979 French height velocity growth charts for girls (A) and boys (B), from age 13 months to 15 years.

(Paris area) and under favourable nutritional and socioeconomic conditions. These children were healthier than the general population at inclusion, and the attrition in this cohort was high, from 588 neonates to 171 children, whereas children who remain in birth cohorts tend to live in families with high socioeconomic conditions.[44] Thus, the new height velocity growth charts could better describe a greater variability that already existed six decades ago but that was not captured given the strong selection bias of the studied population then used.

4.2 | Strengths and limitations

Compared to height velocity growth charts previously derived, the new annual and biannual height velocity growth charts from age 1 month to 15 years were based on a national, recent and very large sample of about 90000 children living in France, using routine data collected by PCPs. This highly original approach has some limitations. First, the recruitment mainly relying on primary care paediatricians might have introduced a selection bias: included children who were likely to live in better socioeconomic conditions and be exposed to better energy balance–related behaviours than the general population.[45] To limit this bias, we also collected data from the medical software of non-randomly selected general physicians. However, we cannot make a clear hypothesis about the direction of such bias regarding height velocity.

Second, contrary to the children used for deriving the 1979 French height velocity growth charts,[7–26] the children used for the new growth charts were measured on a routine basis, without a strict protocol of data collection by trained specialists. This difference may have resulted in more measurement errors and intra-individual variability between consecutive consultations and may have contributed to the higher dispersion observed. We could not estimate these measurement errors, but we applied a thorough cleaning process to limit their impact as much as possible.

Third, children with a chronic condition that may affect height and height velocity, including those with early or late puberty, should have ideally been screened and excluded. Unfortunately, this strategy was not possible given the mode of data collection in our study and the type of data collected. We attempted to limit this bias by excluding data for children with extremely abnormal height, weight or head circumference or an excessive number of height, weight or head circumference measurements (see Figure S3). All these potential biases are probably modest given that new height growth charts derived from the initial population were almost perfectly calibrated to large national cross-sectional surveys performed in schools.[29]

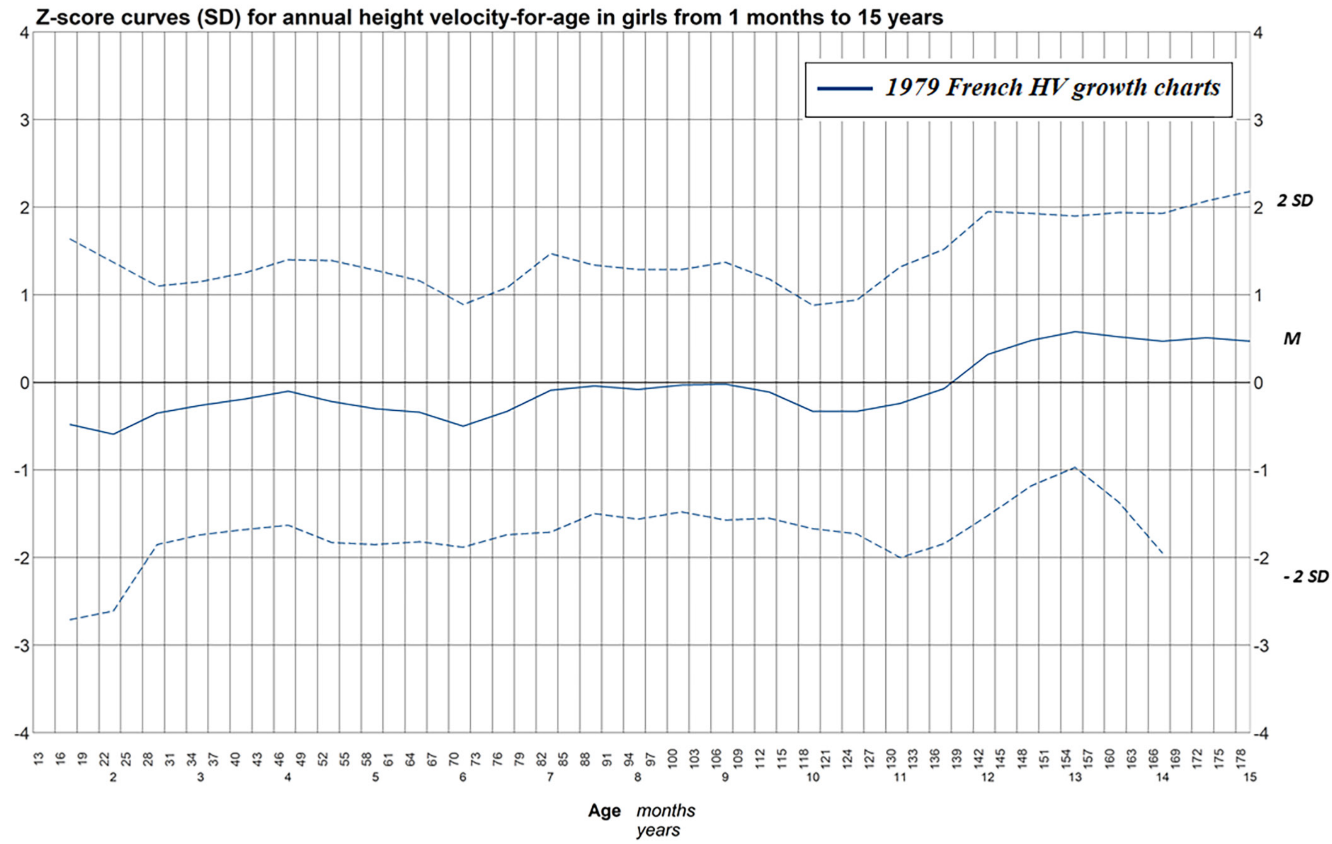
Fourth, in our very large dataset of height measurements, we could calculate a high number of growth velocities values in the early years of life compared to other studies, but this number decreased with age and was ultimately very low after 15 years, as also observed in previous studies (Table S1). Therefore, we had to truncate the height velocity growth charts after this age. This shortcoming will prevent monitoring health events or treatments occurring in adolescence, such as delayed puberty, notably in boys, in whom this condition is more frequent. In addition, the Lambda-Mu-Sigma method used with generalised additive models for location, scale and shape to generate the height velocity growth charts was suggested to underestimate the mean height velocity growth spurt.[46] Nevertheless, the Lambda-Mu-Sigma method has been used to derive all currently available height velocity growth charts (see Table S1).[18,20–22,24,25] Other methods, such as the SuperImposition by Translation And Rotation (SITAR) model proposed by Cole et al.[47] could help refine the height velocity growth charts to monitor the growth spurt during puberty.[48]

Finally, we chose to generate height velocity growth charts for only 6- and 12-month intervals, an arbitrary time threshold. However, these age intervals have often been used at the national or international levels (see Table S1)[7–11,13,14,17–26] and are also those proposed by the Growth Hormone Research Society for monitoring height growth under growth hormone therapy.[5] Our approach could be used to make height velocity growth charts available for any time interval, as suggested by Hermanussen et al.[49]

4.3 | Implications

Height velocity is considered a key auxological parameter to early detect severe conditions, but it is only used in one of the several clinical decision rules that aim to define abnormal growth: the one proposed by the Growth Hormone Research Society.[1,2] Height velocity is also suggested as a key parameter to monitor growth under treatment such as growth hormone therapy,[50,51] but the height velocity growth charts that should be used for this monitoring are not specified.[1,2] This imprecision may be related to the limits of available height velocity growth charts. The present generation of new height velocity growth charts raises the question of the height velocity growth charts and thresholds that should now be used in day-to-day practice. In France, these new height velocity growth charts are probably adequate to monitor contemporary children until age 15 years. We must now study the clinical impact of the new height velocity growth charts on the clinical performance of growth monitoring. In other countries, the advantages and limits of using these new height velocity growth charts should be balanced against those of alternatives. Any use of the new height velocity growth charts proposed in the present article for children not living in France is cautioned because children's growth trajectories may vary considerably among countries due to differences in environmental and/or nutritional conditions or genetic determinants.[1,27,52] Before the implementation of these new height velocity growth charts in current practice for populations living outside France, an external validation study would probably be

(A)


Z-score curves (SD) for annual height velocity-for-age in girls from 1 months to 15 years
1979 French HV growth charts
2 SD
M
- 2 SD
Age months
years

(B)


Z-score curves (SD) for annual height velocity-for-age in boys from 1 months to 15 years
1979 French HV growth charts
2 SD
M
- 2 SD
Age months
years

FIGURE 4 Z-score curves (SD) of median and ±2 SD values for the 1979 French height velocity growth charts based on the new annual height velocity growth charts, for girls (A) and boys (B), from age 13 months to 15 years. The −2 SD curve was truncated from 174 months for girls because a z-score calculation is not possible in that the −2 SD values of the 1979 French height velocity growth charts are negative after this age. The more the z-scores were close to zero, the more the median values of the 1979 French height velocity growth charts were close to the median values of the new height velocity growth charts.

required and could be eased by the increasing availability of height measurements collected from routine clinical practice. These external validation studies would allow for comparing the fit of the various existing height velocity growth charts (Table S1) to the populations studied in each country. The proof of concept of the big-data approach described here can be applied to any other setting and growth data extracted from medical records databases. The next essential step for optimising growth-monitoring performance would be to account for the differences in terms of SD curves of the new height velocity growth charts by revising the thresholds used to define abnormal height velocity as a single criterion or combined with other growth parameters in clinical decision rules.

5 | CONCLUSION

We produced new annual and biannual national height velocity growth charts until age 15 years by using an innovative approach applied to data routinely collected in clinical practice. The new median curves were close to the 1979 French or 2009 WHO height velocity ones, but SD curves displayed important differences. These new height velocity growth charts could help optimise growth-monitoring performance and detect severe conditions affecting height growth early.

AUTHOR CONTRIBUTIONS

Pauline Scherdel: Conceptualization; formal analysis; writing – original draft; methodology; funding acquisition; software; visualization. **Marion Taine:** Writing – review and editing; investigation. **Manon Bergerat:** Investigation; writing – review and editing. **Andreas Werner:** Writing – review and editing; investigation; resources. **Julien Le Breton:** Investigation. **Michel Polak:** Investigation; writing – review and editing. **Agnès Linglart:** Writing – review and editing; investigation. **Rachel Reynaud:** Investigation; writing – review and editing. **Bruno Frandji:** Writing – review and editing; data curation. **Jean-Claude Carel:** Writing – review and editing; investigation. **Raja Brauner:** Investigation; writing – review and editing. **Martin Chalumeau:** Conceptualization; methodology; writing – original draft; supervision; funding acquisition; validation. **Barbara Heude:** Conceptualization; methodology; writing – original draft; formal analysis; supervision; funding acquisition; validation; project administration.

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CONFLICT OF INTEREST STATEMENT

Barbara Heude, Andreas Werner, Martin Chalumeau, Bruno Frandji and Pauline Scherdel are co-owners of the patent for the new national French AFPA/Inserm/CGM growth charts. Pauline Scherdel, Barbara Heude and Martin Chalumeau received a grant from the Novo-Nordisk society, a manufacturer of growth hormone. Agnès Linglart received honoraria from Alexion, Sandoz, Pfizer, Merck Serono and Novo-Nordisk, and a research grant from Kyowa Kirin. No other relationships or activities that could appear to have influenced the submitted work are declared.

DATA AVAILABILITY STATEMENT

A public–private consortium was required for generating the height velocity growth chart, and therefore these data are protected and patented. Data can be made available on request from the corresponding author via collaborative research projects or under licence.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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