

Modelling growth in dairy heifers based on linear body measurements (withers height) using non-linear functions

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SUPPLEMENTARY FILE

Table S1. Average body weight (BW) and withers height (WH) of U.S. Holstein, Jersey and Brown Swiss heifers adopted from the National Dairy Heifer Evaluation Project (<https://extension.psu.edu/growth-charts-for-dairy-heifers>)

Age (mo)	Holstein heifers			Jersey heifers			Brown Swiss heifers		
	BW (kg)	WH (cm)	BW/WH ratio	BW (kg)	WH (cm)	BW/WH	BW (kg)	WH (cm)	BW/WH ratio
1	64.9	83.8	0.77	49.0	81.3	0.60	73.9	86.4	0.86
2	108.0	94.0	1.15	66.2	83.8	0.79	101.2	91.4	1.11
3	128.8	96.5	1.33	80.3	86.4	0.93	128.4	96.5	1.33
4	153.8	101.6	1.51	98.4	91.4	1.08	155.6	101.6	1.53
5	186.4	106.7	1.75	126.1	96.5	1.31	182.8	106.7	1.71
6	217.7	111.8	1.95	145.6	99.1	1.47	209.6	111.8	1.88
7	245.8	114.3	2.15	164.2	101.6	1.62	236.3	114.3	2.07
8	273.5	119.4	2.29	186.9	104.1	1.79	263.1	116.8	2.25
9	319.8	119.4	2.68	197.8	106.7	1.85	288.9	121.9	2.37
10	352.0	124.5	2.83	219.1	106.7	2.05	314.8	124.5	2.53
11	352.0	124.5	2.83	226.3	109.2	2.07	340.2	127.0	2.68
12	382.4	129.5	2.95	248.6	111.8	2.22	365.1	129.5	2.82
13	414.1	129.5	3.20	259.0	114.3	2.27	389.6	132.1	2.95
14	465.4	132.1	3.52	273.1	114.3	2.39	413.7	132.1	3.13
15	484.0	134.6	3.60	290.3	116.8	2.48	436.8	134.6	3.24
16	497.1	134.6	3.69	299.8	116.8	2.57	459.5	137.2	3.35
17	540.2	137.2	3.94	315.7	119.4	2.64	481.3	137.2	3.51
18	540.2	137.2	3.94	341.6	119.4	2.86	502.1	139.7	3.59
19	580.1	137.2	4.23	348.8	119.4	2.92	522.5	139.7	3.74
20	590.6	144.8	4.08	368.8	121.9	3.02	541.6	142.2	3.81
21	622.3	142.2	4.38	375.1	121.9	3.08	560.2	142.2	3.94
22	644.1	144.8	4.45	390.1	124.5	3.13	577.4	142.2	4.06
23	644.1	144.8	4.45	398.3	124.5	3.20	593.8	144.8	4.10
24	700.8	144.8	4.84	405.1	127.0	3.19	609.2	144.8	4.21
25	-	-	-	-	-	-	623.2	144.8	4.30

Table S2. Mathematical functions used in this study

Function	Functional form ¹	Time at inflexion point	y at inflexion point
Monomolecular	$y = y_f - (y_f - y_0)e^{-ct}$	Not applicable	Not applicable
Michaelis-Menten	$y = \frac{y_0 K + y_f t}{K + t}$	Not applicable	Not applicable
Schumacher	$y = y_f \times \exp\left(\frac{-cb^2}{t + b}\right)$	$b\left(\frac{bc}{2} - 1\right)$	$\frac{y_f}{e^2}$
Lopez	$y = \frac{y_0 K^n + y_f t^n}{K^n + t^n}$	$K\left(\frac{n-1}{n+1}\right)^{\frac{1}{n}}$	$\frac{\left(1 + \frac{1}{n}\right)y_0 + \left(1 - \frac{1}{n}\right)y_f}{2}$

¹ y = withers height (WH) or body weight to WH ratio, y₀ = initial WH or BW:WH, y_f = asymptotic WH or BW:WH, t = age; c, K, b and n are parameters.

Table S3. Parameter estimates for dairy cow heifers estimated using the different functions

Function	Parameter ¹	Holstein		Jersey		Brown Swiss	
		WH vs. age	BW:WH vs. age	WH vs. age	BW:WH vs. age	WH vs. age	BW:WH vs. age
Monomolecular	<i>c</i>	0.0904	0.0369	0.0818	0.0468	0.0969	0.0378
	<i>y</i> ₀	79.56	0.5727	75.92	0.4111	78.69	0.6738
	<i>y</i> _f	153.36	7.59	133.18	4.62	151.90	6.61
Michaelis-Menten	<i>K</i>	12.50	43.12	14.79	31.72	11.51	41.25
	<i>y</i> ₀	77.27	0.5541	74.67	0.3872	76.52	0.6537
	<i>y</i> _f	181.14	12.17	156.98	7.05	178.52	10.35
Lopez	<i>K</i>	14.57	38.49	12.39	34.73	9.10	50.26
	<i>n</i>	0.8921	1.03	1.15	0.9719	1.40	0.9512
	<i>y</i> ₀	74.74	0.580	76.50	0.369	83.11	0.616
	<i>y</i> _f	191.34	11.41	148.23	7.40	160.52	11.51
	<i>y</i> [*]	67.69	0.737	81.07	0.268	94.23	0.336
	<i>t</i> [*]	NA ²	0.67	1.19	NA	2.55	NA
Schumacher	<i>c</i>	0.1039	0.3055	0.0730	0.3402	0.1117	0.2531
	<i>b</i>	8.11	8.79	10.09	7.54	7.50	9.72
	<i>y</i> ₀	77.52	0.66	74.77	0.46	76.78	0.73
	<i>y</i> _f	180.04	9.61	156.13	5.99	177.57	8.55
	<i>y</i> [*]	24.37	1.03	21.13	0.82	24.03	1.16
	<i>t</i> [*]	-4.69	3.01	-6.37	2.13	-4.36	2.24

¹ *y* = withers height (WH) or body weight to WH ratio; *y*₀ = initial WH or BW:WH; *y*_f = asymptotic WH or BW:WH; *y*^{*} and *t*^{*} define the inflexion point; *c*, *K*, *n* and *b* are parameters.

² NA = Non-applicable.

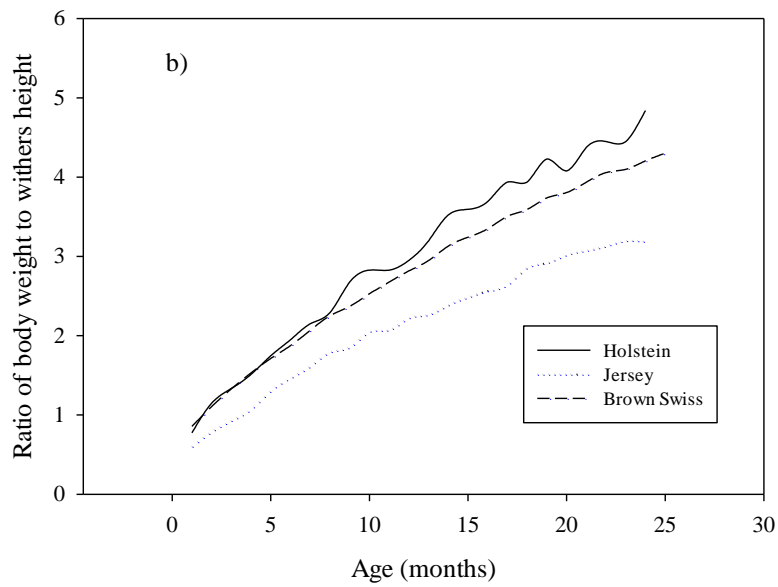
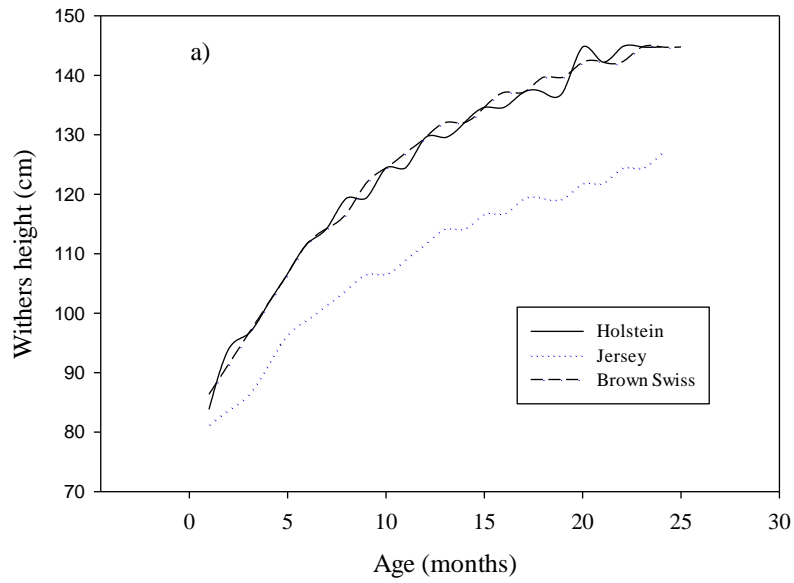


Fig. S1. Observed plots of withers height (a) and of body weight to withers height ratio (b) against age in three breeds of dairy heifer.

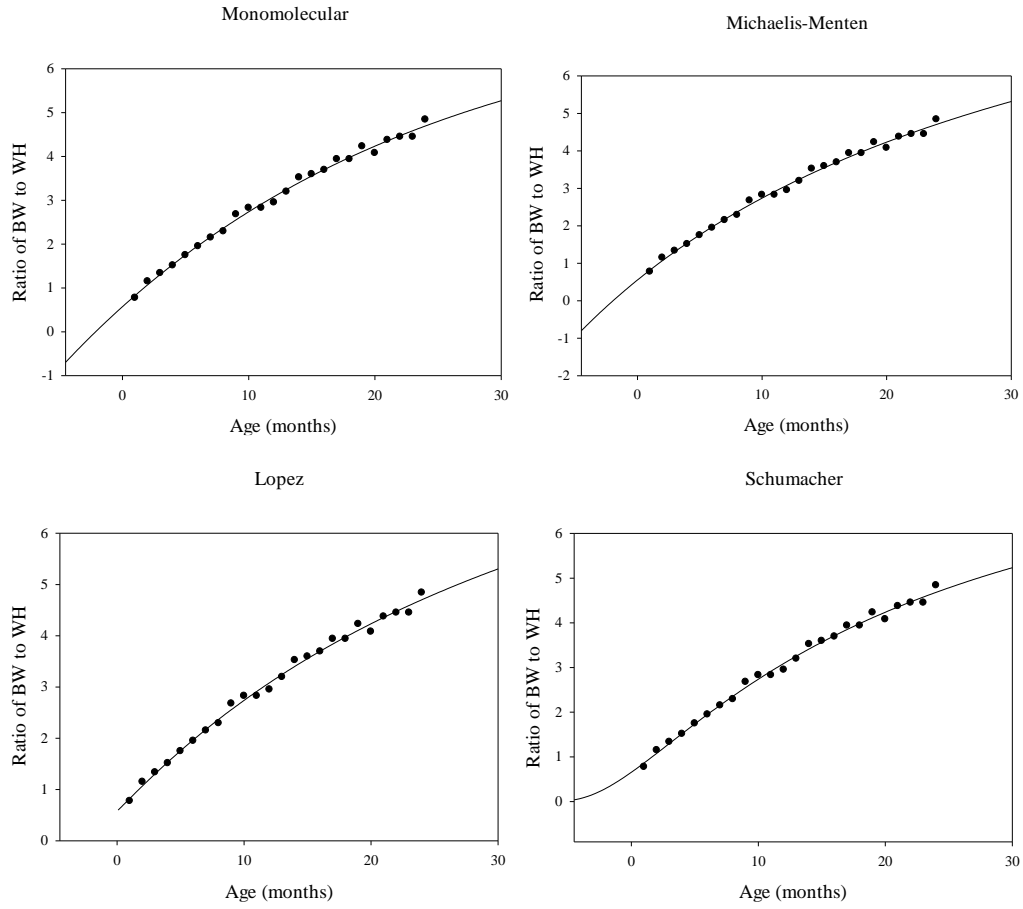


Fig. S2. Plots of body weight (BW, kg) to withers height (WH, cm) ratio against age (mo) showing the fit of different functions to the data on Holstein heifers.