Hydration-dependent failure resistance of radular teeth in the neritid gastropod *Vittina turrita*

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Supplementary Materials

Supplementary Table S1. Breaking force, time to first structural failure, and characteristic failure patterns of the investigated radular tooth types of *Vittina turrita* under dry and wet conditions. Quantitative values are means ± SD calculated from specimen means (n = 15 specimens per hydration condition; 20 tooth tests per tooth type and specimen). Failure descriptions summarize qualitative experimental observations.

Tooth type	Condition	Breaking force, mean ± SD (mN)	Time to first structural failure, mean ± SD (s)	Observed failure pattern in most cases
Lateral teeth I	Dry	755.7 ± 27.0	0.45 ± 0.02	Bridge-like region; diffuse crumbling/fragmentation
Lateral teeth I	Wet	949.3 ± 47.3	0.58 ± 0.02	Small localized damage at bridge-like region
Lateral teeth II	Dry	843.4 ± 31.1	0.68 ± 0.04	Cusp
Lateral teeth II	Wet	1071.5 ± 54.0	0.82 ± 0.05	Variable: cusp, stylus, or basis
Inner marginal teeth	Dry	569.8 ± 19.8	0.92 ± 0.06	Cusp
Inner marginal teeth	Wet	717.8 ± 33.9	1.10 ± 0.07	Basis
Medial marginal teeth	Dry	518.5 ± 18.6	1.18 ± 0.06	Cusp
Medial marginal teeth	Wet	671.9 ± 39.3	1.40 ± 0.08	Basis
Outer marginal teeth	Dry	474.9 ± 19.2	1.48 ± 0.08	Cusp
Outer marginal teeth	Wet	607.4 ± 39.7	1.75 ± 0.10	Basis

Supplementary Table S2. Descriptive statistics for breaking force and time to first structural failure of *Vittina turrita* radular teeth. Statistics are based on specimen-level means, with 15 specimens per hydration condition and 20 tooth measurements per tooth type and specimen. SEM and 95% confidence intervals refer to variation among specimen means.

Condition	Tooth type	n specimens	n teeth	Force mean ± SD (mN)	SEM	95% CI (mN)	Time mean ± SD (s)	SEM	95% CI (s)
Dry	Lateral teeth I	15	300	755.68 ± 26.97	6.96	740.74–770.61	0.450 ± 0.019	0.005	0.439–0.461
Dry	Lateral teeth II	15	300	843.39 ± 31.12	8.04	826.16–860.63	0.680 ± 0.041	0.011	0.657–0.702
Dry	Inner marginal teeth	15	300	569.78 ± 19.78	5.11	558.82–580.73	0.920 ± 0.062	0.016	0.885–0.954
Dry	Medial marginal teeth	15	300	518.53 ± 18.65	4.81	508.20–528.86	1.180 ± 0.064	0.017	1.145–1.216
Dry	Outer marginal teeth	15	300	474.92 ± 19.22	4.96	464.28–485.56	1.480 ± 0.078	0.020	1.437–1.524
Wet	Lateral teeth I	15	300	949.33 ± 47.31	12.21	923.14–975.53	0.580 ± 0.022	0.006	0.568–0.592
Wet	Lateral teeth II	15	300	1071.50 ± 54.00	13.94	1041.59–1101.41	0.820 ± 0.046	0.012	0.794–0.845
Wet	Inner marginal teeth	15	300	717.83 ± 33.86	8.74	699.08–736.58	1.100 ± 0.073	0.019	1.060–1.141
Wet	Medial marginal teeth	15	300	671.92 ± 39.28	10.14	650.17–693.67	1.400 ± 0.084	0.022	1.354–1.446
Wet	Outer marginal teeth	15	300	607.37 ± 39.73	10.26	585.36–629.37	1.750 ± 0.100	0.026	1.694–1.805

Supplementary Table S3. Distributional diagnostics for specimen-level mean breaking force and time to first structural failure. Group-wise Shapiro-Wilk tests are shown for each tooth type × hydration combination (n = 15 specimens per group), followed by Shapiro-Wilk tests of model residuals and Brown-Forsythe tests of variance homogeneity.

Response	Condition	Tooth type	W	*p*
Breaking force	Dry	Lateral teeth I	0.940	0.381
Breaking force	Dry	Lateral teeth II	0.953	0.578
Breaking force	Dry	Inner marginal teeth	0.971	0.873
Breaking force	Dry	Medial marginal teeth	0.960	0.684
Breaking force	Dry	Outer marginal teeth	0.964	0.770
Breaking force	Wet	Lateral teeth I	0.949	0.512
Breaking force	Wet	Lateral teeth II	0.914	0.154
Breaking force	Wet	Inner marginal teeth	0.951	0.537
Breaking force	Wet	Medial marginal teeth	0.951	0.537
Breaking force	Wet	Outer marginal teeth	0.965	0.772
Time to first structural failure	Dry	Lateral teeth I	**0.862**	**0.026**
Time to first structural failure	Dry	Lateral teeth II	0.961	0.703
Time to first structural failure	Dry	Inner marginal teeth	0.940	0.379
Time to first structural failure	Dry	Medial marginal teeth	0.981	0.979
Time to first structural failure	Dry	Outer marginal teeth	0.884	0.054
Time to first structural failure	Wet	Lateral teeth I	0.956	0.619
Time to first structural failure	Wet	Lateral teeth II	0.971	0.866
Time to first structural failure	Wet	Inner marginal teeth	0.956	0.629
Time to first structural failure	Wet	Medial marginal teeth	0.974	0.913
Time to first structural failure	Wet	Outer marginal teeth	0.977	0.946

Additional model diagnostics

Response	Test	Statistic	*p*
Breaking force	Shapiro–Wilk, model residuals	W = 0.988	0.206
Time to first structural failure	Shapiro–Wilk, model residuals	W = 0.986	0.148
Breaking force	Brown–Forsythe test	F = 3.19	0.0015
Time to first structural failure	Brown–Forsythe test	F = 4.62	<0.0001

Supplementary Table S4. Effects of hydration condition, tooth type, and their interaction on breaking force and time to first structural failure. Gaussian generalized estimating equations were fitted to specimen-level means with specimen as the clustering variable, an exchangeable within-specimen correlation structure and robust sandwich standard errors. Type III Wald tests used sum-to-zero effect coding.

Response	Effect	Wald χ^2	df	*p*
Breaking force	Hydration	243.66	1	<0.0001
Breaking force	Tooth type	7849.16	4	<0.0001
Breaking force	Hydration × tooth type	85.94	4	<0.0001
Time to first structural failure	Hydration	229.28	1	<0.0001
Time to first structural failure	Tooth type	10099.04	4	<0.0001
Time to first structural failure	Hydration × tooth type	31.95	4	0.000002

Supplementary Table S5. Model-based post-hoc comparisons between wet and dry conditions within each tooth type. Estimates represent wet minus dry differences derived from the GEE models. Confidence intervals and standard errors are based on robust covariance estimates. P-values were adjusted using the Holm procedure within each response variable.

A. Breaking force

Tooth type	Wet − dry difference (mN)	Robust SE	95% CI (mN)	z	Holm-adjusted *p*
Lateral teeth I	193.66	13.58	167.03–220.28	14.26	<0.0001
Lateral teeth II	228.11	15.55	197.63–258.58	14.67	<0.0001
Inner marginal teeth	148.05	9.78	128.88–167.23	15.14	<0.0001
Medial marginal teeth	153.39	10.85	132.13–174.65	14.14	<0.0001
Outer marginal teeth	132.45	11.01	110.87–154.02	12.03	<0.0001

B. Time to first structural failure

Tooth type	Wet − dry difference (s)	Robust SE	95% CI (s)	z	Holm-adjusted *p*
Lateral teeth I	0.130	0.007	0.116–0.144	17.89	<0.0001
Lateral teeth II	0.140	0.015	0.110–0.170	9.11	<0.0001
Inner marginal teeth	0.180	0.024	0.133–0.227	7.51	<0.0001
Medial marginal teeth	0.220	0.026	0.168–0.271	8.35	<0.0001
Outer marginal teeth	0.270	0.032	0.207–0.332	8.49	<0.0001

Supplementary Table S6. Pairwise post-hoc comparisons among tooth types within dry and wet conditions. Estimates represent the mean of the first-listed tooth type minus that of the second-listed tooth type. Comparisons were derived from Gaussian GEE models with robust covariance estimates. P-values were adjusted separately within each hydration condition using the Holm procedure.

A. Breaking force - Dry condition

Tooth 1	Tooth 2	Difference (mN)	Robust SE	95% CI	z	Holm *p*
Lateral teeth I	Lateral teeth II	−87.72	5.17	−97.85 to −77.58	−16.96	<0.0001
Lateral teeth I	Inner marginal teeth	185.90	4.28	177.51 to 194.28	43.46	<0.0001
Lateral teeth I	Medial marginal teeth	237.15	4.02	229.26 to 245.03	58.95	<0.0001
Lateral teeth I	Outer marginal teeth	280.76	6.19	268.63 to 292.88	45.38	<0.0001
Lateral teeth II	Inner marginal teeth	273.62	6.11	261.65 to 285.58	44.80	<0.0001
Lateral teeth II	Medial marginal teeth	324.87	6.03	313.04 to 336.69	53.84	<0.0001
Lateral teeth II	Outer marginal teeth	368.48	6.80	355.15 to 381.80	54.18	<0.0001
Inner marginal teeth	Medial marginal teeth	51.25	3.96	43.48 to 59.02	12.93	<0.0001
Inner marginal teeth	Outer marginal teeth	94.86	5.12	84.83 to 104.89	18.53	<0.0001
Medial marginal teeth	Outer marginal teeth	43.61	5.75	32.35 to 54.87	7.59	<0.0001

B. Breaking force - Wet condition

Tooth 1	Tooth 2	Difference (mN)	Robust SE	95% CI	z	Holm *p*
Lateral teeth I	Lateral teeth II	−122.17	7.73	−137.31 to −107.03	−15.81	<0.0001
Lateral teeth I	Inner marginal teeth	231.50	6.64	218.49 to 244.51	34.88	<0.0001
Lateral teeth I	Medial marginal teeth	277.41	6.89	263.92 to 290.91	40.28	<0.0001
Lateral teeth I	Outer marginal teeth	341.97	7.57	327.14 to 356.80	45.19	<0.0001
Lateral teeth II	Inner marginal teeth	353.67	7.79	338.41 to 368.93	45.43	<0.0001
Lateral teeth II	Medial marginal teeth	399.58	8.92	382.09 to 417.07	44.77	<0.0001
Lateral teeth II	Outer marginal teeth	464.13	8.64	447.21 to 481.06	53.74	<0.0001
Inner marginal teeth	Medial marginal teeth	45.91	4.37	37.35 to 54.48	10.51	<0.0001
Inner marginal teeth	Outer marginal teeth	110.47	4.32	101.99 to 118.94	25.56	<0.0001
Medial marginal teeth	Outer marginal teeth	64.55	6.60	51.61 to 77.50	9.77	<0.0001

C. Time to first structural failure - Dry condition

Tooth 1	Tooth 2	Difference (s)	Robust SE	95% CI	z	Holm p
Lateral teeth I	Lateral teeth II	−0.230	0.010	−0.249 to −0.210	−23.51	<0.0001
Lateral teeth I	Inner marginal teeth	−0.470	0.013	−0.496 to −0.444	−35.07	<0.0001
Lateral teeth I	Medial marginal teeth	−0.730	0.017	−0.763 to −0.697	−43.40	<0.0001
Lateral teeth I	Outer marginal teeth	−1.030	0.018	−1.066 to −0.994	−56.14	<0.0001
Lateral teeth II	Inner marginal teeth	−0.240	0.016	−0.271 to −0.209	−15.28	<0.0001
Lateral teeth II	Medial marginal teeth	−0.500	0.023	−0.546 to −0.455	−21.37	<0.0001
Lateral teeth II	Outer marginal teeth	−0.800	0.021	−0.841 to −0.760	−38.60	<0.0001
Inner marginal teeth	Medial marginal teeth	−0.260	0.024	−0.306 to −0.214	−11.06	<0.0001
Inner marginal teeth	Outer marginal teeth	−0.560	0.026	−0.612 to −0.508	−21.20	<0.0001
Medial marginal teeth	Outer marginal teeth	−0.300	0.024	−0.348 to −0.252	−12.33	<0.0001

D. Time to first structural failure - Wet condition

Tooth 1	Tooth 2	Difference (s)	Robust SE	95% CI	z	Holm p
Lateral teeth I	Lateral teeth II	−0.240	0.010	−0.260 to −0.220	−23.06	<0.0001
Lateral teeth I	Inner marginal teeth	−0.520	0.017	−0.554 to −0.486	−30.03	<0.0001
Lateral teeth I	Medial marginal teeth	−0.820	0.020	−0.859 to −0.781	−41.09	<0.0001
Lateral teeth I	Outer marginal teeth	−1.170	0.025	−1.219 to −1.121	−46.38	<0.0001
Lateral teeth II	Inner marginal teeth	−0.280	0.022	−0.323 to −0.237	−12.72	<0.0001
Lateral teeth II	Medial marginal teeth	−0.580	0.019	−0.618 to −0.542	−29.89	<0.0001
Lateral teeth II	Outer marginal teeth	−0.930	0.026	−0.981 to −0.879	−35.52	<0.0001
Inner marginal teeth	Medial marginal teeth	−0.300	0.024	−0.347 to −0.252	−12.35	<0.0001
Inner marginal teeth	Outer marginal teeth	−0.650	0.026	−0.700 to −0.600	−25.32	<0.0001
Medial marginal teeth	Outer marginal teeth	−0.350	0.028	−0.405 to −0.295	−12.55	<0.0001

Supplementary Table S7. Qualitative failure locations and failure morphologies observed in most dry and hydrated radular teeth of *Vittina turrita*. Failure patterns are based on experimental observations. Because failure events have not yet been systematically scored, the table summarizes observed patterns rather than frequencies or proportions.

Tooth type	Dry condition	Wet condition	Main hydration-dependent change
Lateral teeth I	Damage at bridge-like connection to central tooth; diffuse crumbling or fragmentation without a distinct fracture plane	Small, localized damage at bridge-like connection	Hydration changes diffuse fragmentation into spatially localized damage
Lateral teeth II	Cusp failure	Variable failure at cusp, stylus, or basis	Failure becomes less spatially localized when hydrated
Inner marginal teeth	Cusp failure	Basal failure	Failure shifts from distal to proximal
Medial marginal teeth	Cusp failure	Basal failure	Failure shifts from distal to proximal
Outer marginal teeth	Cusp failure	Basal failure	Failure shifts from distal to proximal

Supplementary Data S1. Individual tooth-level raw measurements of *Vittina turrita* under dry and rewetted conditions (separate Excel workbook:
Supplementary_Data_S1_Vittina_turrita_raw_measurements.xlsx).
The Excel workbook contains all 3,000 individual measurements from 30 specimens (15 dry and 15 wet). For each specimen, 20 teeth from each of five tooth categories were tested. Each record includes the specimen identifier, hydration condition, tooth type, within-category tooth number, breaking force (mN) and time to first structural failure (s).
Raw-data tooth-type labels are Lateral I (LTI), Lateral II (LTII), Marginal 1 (inner marginal teeth, IMT), Marginal 5 (medial marginal teeth, MMT) and Marginal 8 (outer marginal teeth, OMT).