

Submission ID #: 71757

Scriptwriter Name: Kathyayani Sridharan

Project Page Link: <https://review.jove.com/account/file-uploader?src=21885933>

Title: A Low-Cost Apparatus for Measuring Muscle Force–Velocity Relationships

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Author Questionnaire

- 1. Microscopy:** Does your protocol require the use of a dissecting or stereomicroscope for performing a complex dissection, microinjection technique, or something similar? **No**
- 2. Software:** Does the part of your protocol being filmed include step-by-step descriptions of software usage? **YES**
- 3. Filming location:** Will the filming need to take place in multiple locations? **NO**
- 4. Testimonials (optional):** Would you be open to filming two short testimonial statements **live during your JoVE shoot**? These will **not appear in your JoVE video** but may be used in JoVE's promotional materials. **NO**

Current Protocol Length

Number of Steps: 20

Number of Shots: 55

Interviews

Videographer: Obtain headshots for all authors available at the filming location.

Authors: Please note that **the questions will not appear on screen**. Please answer in **stand-alone full sentence with sufficient context**

Note: The statements have been edited for clarity and length.

INTRODUCTION:

~~**REQUIRED:** Summarize your research focus and the main questions it aims to answer.~~

- 1.1. **Gabriel Crowell:** Our research focuses on the development of an accessible, low-cost apparatus for measuring human muscle force–velocity–power relationships and understanding musculoskeletal functions.

- 1.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

~~Describe the research contexts or systems in which this protocol can be applied.~~

- 1.2. **Gabriel Crowell Nicolai Konow:** This protocol brings authentic muscle physiology experiments into classrooms, teaching laboratories, and resource-limited learning environments around the world.

- 1.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

CONCLUSION:

~~What does this protocol allow researchers to study or measure?~~

- 1.3. **Nicolai Konow:** This protocol provides accessible experimental tools, enabling anyone to collect and analyze real muscle force, velocity, and power data.

- 1.3.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

~~Describe the most important consideration or challenge when performing this protocol.~~

- 1.4. **Gabriel Crowell:** Achieving accurate results requires careful setup, consistent technique, and ensuring participants maintain maximal effort throughout all muscle contractions.

- 1.4.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

~~How can future studies build on this work? Describe the questions or research directions that can be investigated next.~~

- 1.5. **Gabriel Crowell**: Future iterations using recycled materials will democratize force–velocity–power research in educational settings lacking expensive ergometry and 3D-printing resources.
 - 1.5.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

Videographer: Obtain headshots for all authors available at the filming location.

Ethics Title Card

This research has been approved by the Institutional Review Board (IRB) at the University of Massachusetts Lowell

Protocol

***Videographer:** Please always record an audio slate while filming each shot mentioned in the shotlist.*

2. Low-Cost Apparatus Assembly for Measuring Muscle Force–Velocity Relationships

Demonstrators: Gabriel Crowell, Nicolai Konow, Vivi Nguyen, Dan Bartlett

***Video Editor:** All demonstrators, including non-authors are affiliated to University of Massachusetts, Lowell*

2.1. To begin, attach two short aluminum beams to the underside of one long aluminum beam using aluminum frame fasteners [1]. Position the short beams approximately 8 centimeters from each end of the long beam to form a stable, noncompliant base, referring to this assembly as the frame [2].

2.1.1. WIDE: Talent attaching two short aluminum beams to the underside of one long aluminum beam using aluminum frame fasteners.

2.1.2. Talent positioning the short aluminum beams approximately 8 centimeters from each end of the long aluminum beam. *Videographer: Please capture a shot of the completed frame also.* **Videographer's NOTE:** The first shot we filmed was of the completed device with all the components. I slated it as 2.1.2 but most likely belongs around 2.11.5 or for an added 2.11.6 We did get a shot of the completed frame for 2.1.2 as well (C3426.MP4)

2.2. Position a large cellular polyvinyl chloride, or PVC (*P-V-C*), block with the 7-inch side oriented vertically and the 6.75-inch side oriented horizontally [1]. Measure 2.75 inches from the bottom-left corner along the left edge and mark the location [2]. Measure 2.75 inches from the top-left corner along the top edge and mark the location [3].

Videographer's NOTE: File C3427.MP4 was tail slated as 2.2.1 but is actually 2.2.1 - 2.3.1

2.2.1. Talent positioning the large cellular polyvinyl chloride block in the required orientation. *Videographer: include a close-up of the block orientation.*

2.2.2. Talent measuring and marking 2.75 inches from the bottom-left corner along the left edge. *Videographer: capture a close-up of the ruler/square and the pencil marks.*

2.2.3. Talent measuring and marking 2.75 inches from the top-left corner along the top edge. *Videographer: capture a close-up of the ruler/square and the pencil marks.*

2.3. Draw a straight line connecting the two marked locations [1]. Cut along the marked line and remove the resulting triangular section [2]. Drill a 7/16 (*seven-sixteenths*)-inch hole 1.25 inches from the top-right corner [3], repeating the whole procedure to prepare the second large cellular PVC block [4].

- 2.3.1. CU: Talent drawing a straight line between the two marked locations.
- 2.3.2. CU: Talent cutting along the marked line and removing the triangular section.
- 2.3.3. CU: Talent drilling a 7/16-inch hole 1.25 inches from the top-right corner.
- 2.3.4. Shot of the pre-fabricated second large PVC block — already cut and drilled, shown ready-made.
- 2.4. Secure the 2 large blocks to the small block so they are 8 inches apart, with the diagonal cuts above the small block and the drilled holes beyond its edge [1]. Position the small cellular PVC block behind the frame [2]. Clamp the pulley mount securely to the corner of a table or counter, positioning it so that the pulley extends beyond the edge of the table [3].
 - 2.4.2, Talent securing both large blocks to the small block with the specified orientation and spacing.
 - 2.4.1. Talent positioning the small cellular PVC block behind the frame. **NOTE: Flip 2.4.2 and 2.4.1 so that the blocks were attached together and then placed behind the frame**
 - 2.4.3,. Talent clamping the pulley mount to the corner of a table or counter.
- 2.5. Next, cut the 14-inch cellular PVC armrest block into two 1.5-inch sections and one 3.5-inch section, cut a 2-inch by 1/8 (*one-eighths*)-inch notch into the top surface of each smaller section, positioning the notch 1 inch from the front edge [1]. **(Authors: Please specify if this is pre-fabricated. If yes, please specify if this shot does not need to be filmed. We can remove this shot accordingly. RESPONSE: This is prefabricated and the shot can be left in.)**
 - 2.5.1. Talent presenting the pre-cut armrest sections, with notches already prepared.
- 2.6. Secure the smaller sections to the underside of the larger section at each end and align the notches with one another [1]. Cover the upper surface of the larger section with hook-and-loop fastener tape [2]. Thread the forearm strap through the two notches [3].
 - 2.6.1. Talent securing the smaller sections to the underside of the larger section with the notches aligned.
 - 2.6.2. Talent applying hook-and-loop fastener tape to the upper surface of the larger section.
 - 2.6.3. Talent threading the forearm strap through the two notches.
- 2.7. Attach the armrest to the frame using bolts and drop-in T-nuts [1]. Position the armrest 14 inches from the pulley mount with the forearm strap facing away from the pulley [2]. Insert ball bearings into the grooves of the inner and outer gears [3].
 - 2.7.1. Talent attaching the armrest to the frame using bolts and drop-in T-nuts.**Videographer's NOTE: File C3417.MP4 slated as 2.7.1 also contains 2.7.2**

- 2.7.2. Talent positioning the armrest 14 inches from the pulley mount with the forearm strap facing away from the pulley.
- 2.7.3. Talent inserting ball bearings into the grooves of the inner gear and outer gear components.
- 2.8. Thread 40 centimeters of timing belt through the lateral slot of the inner gear component and create a loop with a 2-centimeter overlap secured within the slot [1]. Insert the metal axle through the left pulley mount, a stopper, the inner gear component, the force-carry component, the outer gear component, a second stopper, and the right pulley mount [2]. Orient the lateral slot of the inner gear toward the frame and position both stoppers 1 millimeter from either side of the pulley assembly [3].

Videographer's NOTE: 2.8.1 was unslated - file C3411.MP4

C3412.MP4 slated as 2.8.2 also included 2.8.3 and 2.9.1

- 2.8.1. Talent threading the timing belt through the inner gear component and securing the loop within the slot.
- 2.8.2. Talent inserting the metal axle through the pulley assembly components.
- 2.8.3. Talent orienting the inner gear component and positioning the stoppers.
- 2.9. Install two additional stoppers on the axle, positioning each stopper 1 millimeter from the pulley mounts to prevent lateral movement [1]. Loop 40 centimeters of multistrand steel wire through the finger brace, securing it with a crimp [2]. Next, loop the opposite end through Carabiner A and secure it with a second crimp [3].
 - 2.9.1. Talent installing two additional stoppers on the axle.
 - 2.9.2. Talent looping the multistrand steel wire through the finger brace before securing the end with a crimp.
 - 2.9.3. Talent looping the opposite end of the multistrand steel wire through the Carabiner A and securing it with a second crimp.
- 2.10. Connect the inner gear component to Carabiner A using the attached timing belt and secure the overlap with Key A [1]. Loop 10 centimeters of multistrand steel wire around Carabiner A and secure it with a crimp [2]. Next, loop the opposite end around an aluminum frame fastener, crimp the wire, and secure the fastener to the frame [3].
 - 2.10.1. Talent connecting the inner gear component to Carabiner A using the timing belt and Key A.
 - 2.10.2. Talent securing the multistrand steel wire around Carabiner A, securing it with crimp.
 - 2.10.3. Talent looping the opposite end around the aluminum frame fastener, crimping it and securing the fastener to the frame.

2.11. Create a loop using 40 centimeters of timing belt with a 2-centimeter overlap, and insert it into Key B [1]. Then loop the opposite end around Carabiner B and secure the overlap using Key C [2]. Insert Key B into the largest tier of the outer gear component [3]. Suspend the desired starting weight from Carabiner B using a looped and crimped steel wire [4]. Attach the smartphone armband holder to Carabiner B using either the armband loop or the headphone-cable openings [5]. **NOTE: VO flipped**

2.11.1. Talent creating the timing belt loop and inserting it into Key B.

2.11.2. Talent looping the opposite end around Carabiner B, securing it with Key C.

2.11.3. Talent inserting Key B into the largest tier of the outer gear component.

2.11.5., Talent suspending the starting weight from Carabiner B using a looped and crimped steel wire.

2.11.4. Talent attaching the smartphone armband holder to Carabiner B.

Videographer's NOTE: 2.11.5 the weight being added should come before 2.11.4 when the smartphone holder is attached (author request)

2.12. For the data-acquisition setup, install the data-acquisition application on a smartphone equipped with an accelerometer [1]. Open the **Acceleration (without g) (acceleration without G)** module [2]. Place the smartphone in the armband holder attached to Carabiner B, prior to data collection and export [3].

2.12.1. SCREEN: 71757 Screenshot_1 00:09-00:11.

(**Authors:** Please note that commercial names of applications wouldn't be shown in the video, as per the journal guidelines. Therefore, if the screen capture shows such commercial names, they will be blurred or cropped.)

Response: Thank you for that clarification. The use of the freeware Phyphox is essential for this process. Is there a way it can be shown on screen in some way? Perhaps just the app logo, so it's clear that the correct app is being installed?

2.12.2. SCREEN: 71757 Screenshot_1 00:11-00:17. .

2.12.3. Talent placing the smartphone in the armband holder attached to Carabiner B.

Videographer: Please record the computer screen for the shots labeled as SCREEN as back-up

3. Data Acquisition Using Assembled Low-Cost Apparatus

3.1. Use the forearm strap to secure the participant's forearm to the armrest, tightening sufficiently to prevent the arm from moving forward [1]. Place the finger brace on the participant's thumb and tighten the brace securely [2].

3.1.1. WIDE: Talent securing the participant's forearm to the armrest using the forearm strap and tightening it.

- 3.1.2. Talent placing the finger brace on the participant's thumb and tightening the brace.
- 3.2. Remove slack from the pulley system by rotating the pulley through the ratchet mechanism until the timing belt is taut [1]. Slide the safety bolt toward the pulley until the wire connecting the safety bolt and Carabiner A is taut [2]. Select two weights of approximately equal mass, each weighing approximately 1.25 kilograms [3].
 - 3.2.1. Talent rotating the pulley through the ratchet mechanism to tighten the timing belt.
 - 3.2.2. Talent sliding the safety bolt toward the pulley until the connecting wire is taut.
 - 3.2.3. Talent selecting two weights of approximately 1.25 kilograms each.
- 3.3. Test the largest tier, the middle tier, and the smallest tier using one weight and the smartphone [1]. Next, test the smallest, middle, and largest tiers using two weights and the smartphone [2]. Finally, test the largest and smallest tiers using only the smartphone, in a fixed sequence for all participants to minimize fatigue-related bias [3].
 - 3.3.1. Talent testing the largest, middle, and smallest pulley tiers using one weight and the smartphone.
 - 3.3.2. Talent testing the smallest, middle, and largest pulley tiers using two weights and the smartphone.
 - 3.3.3. Talent testing the largest and smallest pulley tiers using only the smartphone.

Author's NOTE: Shots 3.3.1, 3.3.2, and 3.3.3 were filmed as follows: a set of contractions, different weights being added to carabiner B, and the key moving to the different tiers of the pulley.

The original script narration still holds good, but the recorded video is slightly different. I recommend cutting up our video of the different weights and different gears to match each section of the script.

However, we wanted to record them separately because they are shot from different perspectives.
- 3.4. Start Recording in the data acquisition application [1]. Instruct the participant to contract the thumb as rapidly and forcefully as possible [2].
 - 3.4.1. SCREEN: 71757 Screenshot_2 00:02-00:06 .
 - 3.4.2. Talent instructing the participant to contract the thumb as rapidly and forcefully as possible.
- 3.5. Pause data recording after each trial, adjusting the pulley tier and loading condition as per the previously established testing sequence [1]. Resume data recording and repeat the testing procedure until all 8 pulley-tier and loading combinations have been completed [2].

3.5.1. SCREEN: 71757 Screenshot_2 00:20-00:27. .

3.5.2. SCREEN: 71757 Screenshot_2 00:54-01:05 and 02:05-02:07.

3.6. Monitor the participant throughout testing and repeat trials affected by excessive arm movement or incomplete effort [1]. Review the acceleration trace after each trial [2]. Record notes for each trial, including repeated or excluded trials, to facilitate subsequent data analysis and comparison with gold-standard ergometer apparatus [3].

3.6.1. Talent monitoring the participant and repeating a trial when necessary.

3.6.2. Shot of The acceleration trace being reviewed after a trial.

3.6.3. Shot of Show recording notes for each trial, including repeated or excluded trials.

Videographer: Please record the computer screen for the shots labeled as SCREEN as back-up

4. Data Acquisition Using the Gold-Standard Ergometer

Videographer: Please record the computer screen for the shots labeled as SCREEN as back-up

4.1. To validate the low-cost apparatus, record the same thumb contractions on a gold-standard dual-mode lever ergometer, the reference instrument for muscle force–velocity measurement [1]. Connect the finger brace to the lever arm and secure the participant's forearm, aligning the thumb under light tension [2].

4.1.1. WIDE: Show the gold-standard dual-mode lever ergometer and its control software.

4.1.2. Talent connecting the finger brace to the lever arm and aligning the participant's thumb.

4.2. Instruct the participant to contract the thumb as rapidly and forcefully as possible while force and length are recorded [1-TXT]. ~~Reduce the load after each trial and repeat until the lever moves freely, then extract peak force and velocity [2].~~

4.2.1. Talent instructing the participant to contract the thumb on the ergometer.
TXT: Refer to the supplemental coding file 2 for the peak force and peak velocity analysis

4.2.2. **SCREEN:** Force and length being recorded and peak values extracted in the control software. **Author's NOTE: Remove this**

Results

5. Results

- 5.1. Force–velocity [1] and power–velocity data collected from 15 participants using [2] both the gold-standard ergometer [3] and the low-cost apparatus showed similar values without significant differences [4].

5.1.1. LAB MEDIA: Figure 3. *Video Editor: Please emphasize A*

5.1.2. LAB MEDIA: Figure 3. *Video Editor: Please emphasize B*

5.1.3. LAB MEDIA: Figure 3. *Video Editor: Please emphasize the prominent yellow lines in both A and B*

5.1.4. LAB MEDIA: Figure 3. *Video Editor: Please emphasize the prominent blue lines in both A and B*

NOTE: Use the updated Figure 5 for the video (present on project page with the file name Figure 5_updated_use this)

NOTE: Use the updated Table 1 from the JoVE website: <https://review.jove.com/t/71757/a-low-cost-apparatus-for-measuring-muscle-forcevelocity-relationships?status=a73763k>

- 5.2. The five force–velocity–power summary variables did not differ significantly between apparatuses [1]. Peak force, or Fmax (*F-max*) of the human flexor pollicis brevis, averaged at 103 Newtons for the gold-standard ergometer [2] and 104 Newtons for the low-cost apparatus [3], with no significant difference detected between apparatuses [4].

5.2.1. LAB MEDIA: Figure 5B-F *Video editor: Please use the file “Figure 5_updated Use this”*

5.2.2. LAB MEDIA: Table 1. *Video Editor: Please emphasize the value 102.99 ± 29.08 in the third column corresponding to the row labeled “Fmax (Predicted) (N)”*

5.2.3. LAB MEDIA: Table 1. *Video Editor: Please emphasize the value 104.05 ± 36.25 in the second column corresponding to the row labeled “Fmax (Predicted) (N)”*

5.2.4. LAB MEDIA: Table 1. *Video Editor: Please emphasize the value 0.93 in the fourth column corresponding to the row labeled “Fmax (Predicted) (N)”*

- 5.3. Peak velocity or Vmax (*V-max*) averaged 1153 millimeters per second for the gold-standard ergometer [1] and 981 millimeters per second for the low-cost apparatus [2], with no significant difference detected [3].

- 5.3.1. LAB MEDIA: Table 1. *Video Editor: Please emphasize the value 1152.50 ± 451.04 in the third column corresponding to the row labeled “Vmax (Predicted) (mm/s)”*
- 5.3.2. LAB MEDIA: Table 1. *Video Editor: Please emphasize the value 980.58 ± 524.84 in the second column corresponding to the row labeled “Vmax (Predicted) (mm/s)”*
- 5.3.3. LAB MEDIA: Table 1. *Video Editor: Please emphasize the value 0.36 in the fourth column corresponding to the row labeled “Vmax (Predicted) (mm/s)”*

- 5.4. Peak power, or Pmax (*P-max*), averaged 10.9 Watts for the gold-standard ergometer [1] and 12.7 Watts for the low-cost apparatus [2], without a significant difference [3]. Optimal velocity measured at Pmax, averaged 357 millimeters per second for the gold-standard ergometer [4] and 327 millimeters per second for the low-cost apparatus [5].
 - 5.4.1. LAB MEDIA: Table 1. *Video Editor: Please emphasize the value 10.81 ± 6.71 in the third column corresponding to the row labeled “Peak Power (Pmax) (W)”*
 - 5.4.2. LAB MEDIA: Table 1. *Video Editor: Please emphasize the value 12.67 ± 9.45 in the second column corresponding to the row labeled “Peak Power (Pmax) (W)”*
 - 5.4.3. LAB MEDIA: Table 1. *Video Editor: Please emphasize the value 0.55 in the fourth column corresponding to the row labeled “Peak Power (Pmax) (W)”*
 - 5.4.4. LAB MEDIA: Table 1. *Video Editor: Please emphasize the value 357.06 ± 102.67 in the third column corresponding to the row labeled “Velocity at Pmax (mm/s)”*
 - 5.4.5. LAB MEDIA: Table 1. *Video Editor: Please emphasize the value 327.39 ± 151.56 in the second column corresponding to the row labeled “Velocity at Pmax (mm/s)”*

- 5.5. The force–velocity curvature averaged 0.89 for the gold-standard ergometer [1] and 0.69 for the low-cost apparatus [2], without a significant difference between apparatuses, indicating that the overall shapes of the force–velocity curves generated by the two systems were statistically indistinguishable [3]. **(Authors: We have updated these values as per your response. Please update these values in the table to align with the narration.)**
 - 5.5.1. LAB MEDIA: Table 1. *Video Editor: Please emphasize the value 0.89 in the third column “Gold standard” corresponding to the row labeled “Curvature (a/Fmax)”*
 - 5.5.2. LAB MEDIA: Table 1. *Video Editor: Please emphasize the value 0.69 in the second column “Low cost apparatus” corresponding to the row labeled “Curvature (a/Fmax)”*

5.5.3. LAB MEDIA: Table 1. *Video Editor: Please emphasize the value 0.29 in the fourth column corresponding to the row labeled “Curvature (α/F_{max})”*

1. Apparatus
Pronunciation link: <https://www.merriam-webster.com/dictionary/apparatus>
IPA: /,æpəˈrætəs/, /,æpəˈreitəs/
Phonetic Spelling: ap·uh·RAT·uhs, ap·uh·RAY·tuhs
2. Noncompliant
Pronunciation link: <https://www.merriam-webster.com/dictionary/noncompliant>
IPA: /,nɑːnkəmˈplaɪənt/
Phonetic Spelling: non·kuhm·PLY·uhnt
3. Polyvinyl chloride
Pronunciation link: <https://www.merriam-webster.com/dictionary/polyvinyl%20chloride>
IPA: /,pɑːliˈvʌməɪl ˈklɔːraɪd/
Phonetic Spelling: pol·ee·VY·nuhl KLOR·ide
4. Prefabricated
Pronunciation link: <https://www.merriam-webster.com/dictionary/prefabricated>
IPA: /,priːˈfæbrɪˌkertɪd/
Phonetic Spelling: pree·FAB·rih·kay·tid
5. Lateral
Pronunciation link: <https://www.merriam-webster.com/dictionary/lateral>
IPA: /ˈlætərəl/
Phonetic Spelling: LAT·uh·ruhl
6. Axle
Pronunciation link: <https://www.merriam-webster.com/dictionary/axle>
IPA: /ˈæksəl/
Phonetic Spelling: AK·suhl
7. Carabiner
Pronunciation link: <https://www.merriam-webster.com/dictionary/carabiner>
IPA: /,kærəˈbiːnər/
Phonetic Spelling: kar·uh·BEE·ner
8. Multistrand
Pronunciation link: No confirmed link found
IPA: /,mʌltiˈstrænd/
Phonetic Spelling: mul·tee·STRAND
9. Data-acquisition
Pronunciation link: No confirmed link found
IPA: /ˈdeɪtə ˌækwəˈzɪʃən/, /ˈdætə ˌækwəˈzɪʃən/
Phonetic Spelling: DAY·tuh ak·wuh·ZISH·uhn, DAT·uh ak·wuh·ZISH·uhn
10. Accelerometer
Pronunciation link: <https://www.merriam-webster.com/dictionary/accelerometer>

- IPA: /ək,selə'ra:mətər/
Phonetic Spelling: ak·sel·uh·RAH·muh·ter
11. Acceleration
Pronunciation link: <https://www.merriam-webster.com/dictionary/acceleration>
IPA: /ək,selə'reɪʃən/
Phonetic Spelling: ak·sel·uh·RAY·shuhn
12. Phyphox
Pronunciation link: No confirmed link found
IPA: /'faɪfə:ks/
Phonetic Spelling: FY·foks
13. Ratchet
Pronunciation link: <https://www.merriam-webster.com/dictionary/ratchet>
IPA: /'rætʃət/
Phonetic Spelling: RATCH·it
14. Ergometer
Pronunciation link: <https://www.merriam-webster.com/dictionary/ergometer>
IPA: /ər'gɑ:mətər/
Phonetic Spelling: er·GAH·muh·ter
15. Force–velocity
Pronunciation link: No confirmed link found
IPA: /'fɔ:rs və'lɑ:səti/
Phonetic Spelling: FORSS vuh·LOSS·uh·tee
16. Flexor
Pronunciation link: <https://www.merriam-webster.com/dictionary/flexor>
IPA: /'fleksər/
Phonetic Spelling: FLEK·ser
17. Pollicis
Pronunciation link: No confirmed link found
IPA: /'pɑ:lɪsɪs/
Phonetic Spelling: PAH·lih·sis
18. Brevis
Pronunciation link: No confirmed link found
IPA: /'brɛvɪs/
Phonetic Spelling: BREV·iss
19. Flexor pollicis brevis
Pronunciation link: No confirmed link found
IPA: /'fleksər 'pɑ:lɪsɪs 'brɛvɪs/
Phonetic Spelling: FLEK·ser PAH·lih·sis BREV·iss
20. Fmax
Pronunciation link: No confirmed link found
IPA: /'ef mæks/
Phonetic Spelling: EF·maks
21. Vmax
Pronunciation link: No confirmed link found

IPA: /'vi: mæks/

Phonetic Spelling: VEE·maks

22. Pmax

Pronunciation link: No confirmed link found

IPA: /'pi: mæks/

Phonetic Spelling: PEE·maks

23. Curvature

Pronunciation link: <https://www.merriam-webster.com/dictionary/curvature>

IPA: /'kɜ:vətʃər/

Phonetic Spelling: KUR·vuh·cher