Supplemental Material

Shape, size, and structure affect obliquely striated muscle function in squid
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Table S1. List of individuals with number of jets involving mantle contraction or hyperinflation used in analysis

Stage	Individual	Contraction (n)	Hyperinflation (n)
Adult	1	28	9
	2	27	15
	3	8	0
	4	32	11
	5	34	11
	6	83	10
	7	46	15
	8	30	16
Hatchling	1	5	0
	2	2	0
	3	6	2
	4	6	0
	5	1	0
	6	4	1
	7	4	0
	8	9	0
	9	2	0
	10	3	0
	11	2	0
	12	2	0
	13	3	0
	14	4	0
	15	6	0
	16	6	3
	17	7	7

2. THE DISTRIBUTION OF OBLIQUELY STRIATED MUSCLES AMONG ANIMALS

Table S2: Invertebrate Phyla with Obliquely Striated Muscle

Phylum	**Reference**
Annelida	e.g., Rosenbluth (1968)
Brachiopoda	Kuga and Matsuno (1988)
Bryozoa	Bouligard (1966)
Chaetognatha	Duvert and Salat (1979)
Echinodermata	Carnevali et al. (1986)
Gastrotricha	Rieger et al. (1974); Teuchert (1974)
Gnathostomulida	Rieger and Mainitz (1977)
Mollusca	Amsellem and Nicaise (1980); Matsuno and Kuga (1989)
Nematoda	e.g., Rosenbluth (1965)
Nematomorpha	Eakin and Brandenburger (1974); Lanzavecchia et al. (1979)
Nemertea	Norenburg and Roe (1998)
Platyhelminthes	MacRae (1965), Ward et al. (1986)
Priapulida	Mattisson et al. (1974)
Rotifera	Bouligard (1966)
Sipunculida	DeEguileor and Valvassori (1977)
Tardigrada	Walz (1974)
Urochordata	Bone and Ryan (1974)

3. EXPLANATION OF THE MATLAB PROGRAM

The model was created in MATLAB r2014b (The Mathworks, Natick, MA) to calculate the force produced, based on the overlap between the thick and thin myofilaments. It first calculates the force for a sarcomere that is the length of one thick myofilament and increases the length incrementally by a unit equal to the distance between myosin heads until the sarcomere no longer produces force. To simplify the calculations, it considers a two-dimensional array of thick and thin filaments. The area of the two-dimensional array is held constant in order to simulate the essentially constant volume of an actual three-dimensional muscle fiber.

The following lengths are prescribed initially (See Fig. S1): thick myofilament (A), two thin myofilaments plus the width of a Z-body (b), bare zone of thick myofilament (BZ), myosin head spacing, number of myofilament pairs (n), and height of the sarcomere. The initial striation angle is prescribed. The area of the sarcomere is the product of the height and initial length of the sarcomere. The transverse distance between thin myofilaments (d) is calculated by dividing the height of the sarcomere by the number of filaments. The length of a line (designated p) connecting the Z-bodies on one side of the sarcomere is calculated by dividing the height of the sarcomere by the sine of the striation angle. The coordinates of the thick and thin myofilaments are calculated as indicated in Fig. S1.

Once the coordinates are determined, the overlap between the thick and thin filaments on each side of a thick filament and hence the number of cross-bridges interacting and force produced is calculated. At shorter sarcomere lengths, crossbridges are considered to not produce force if they are at a position where the thin filament from the opposite side of the sarcomere extends to their location, reflecting the hypothesis that thin myofilaments of opposite polarity interfere with cross-bridge formation (Gordon et al., 1966).

For each new sarcomere length, the height of the sarcomere was recalculated by dividing the area of the sarcomere by the new length. The angle of striation was then recalculated by taking the inverse since of the height of the sarcomere divided by p.

The total force at each length was divided by the maximum force the muscle produced (P_0), as is customary with empirically derived length-tension curves. The length was standardized by L_0, defined as the length at maximum force. The model allows exploration of the variables that are likely to have the greatest effect on length-tension behavior.

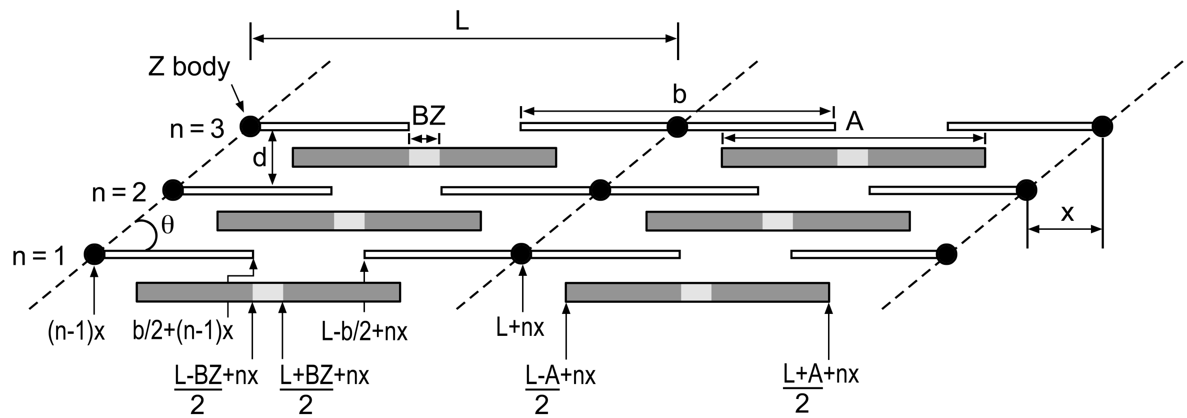

Figure S1 – Obliquely striated sarcomeres with dimensions considered in the model. L = sarcomere length, b= length of two thin myofilaments and one Z-body, x = the horizontal distance between two vertically adjacent thin myofilaments, d = distance beween two thin myofilaments, n = number of thin filament pairs, BZ = length of the bare zone, A = thick myofilament length, θ = angle of striation.

4. MATLAB PROGRAM FOR PREDICTING THE LENGTH-TENSION CURVE OF OBLIQUELY STRIATED MUSCLE

```
function[LTcurve]  = sarc_sim(angle,angle_changing,animate,moviename)

% assign filament dimensions in microns
A = 1.6; % length of the thick filament
I = 2.05; % length of two thin fiaments and a z-line or body
BZ = 0.20; % length of the bare-zone



mh_spacing = 0.02; % spacing between myosin
heads n = 30; % number of thin filaments
h_initial = 6; % initial height of the sarcomere
area = A*h_initial; % area is the initial length of the sarcomere (A)
times the intial height of the sarcomere (h)
p = h_initial/sin(angle/180*pi);  % other side of the parallelogram

% create figure for the
animation if animate
    fig = figure;
    hold on
    h1 = []; % dummy handle for some figure graphic
end

% create movie container if called
for if exist('moviename','var')
    mov = VideoWriter([moviename,'.avi']);
    open(mov);
end

% find the force at each sarcomere length
LF = zeros(round(2*I/mh_spacing)+1,2);  % create an array in which to store
Length and
Tension l = 1;
for L = A:mh_spacing:A+4*I
    h = area/L; % calculate the height of the sarcomere

    d = h/n; % calculate the distance between the filaments based on area
and length.


    % if the angle is changing, calculate the angle of
    striation if angle_changing
        theta = asin(h/p);
```

```
    else
        theta = angle/180*pi;
    end

    x = d/tan(theta); % calculate the lateral distance between the start
 of thin filaments

    % create arrays to hold the locations of the filaments
    TFL = zeros(n-1,round((A-BZ)/2/mh_spacing)+1,2); % create an array to
hold the locations of the left myosin heads
    % fill in array for myosin
    heads for i = 1:n-1
        k = 1;
        for j = (L-A)/2 + x*i:mh_spacing:(L-BZ)/2  + x*i
            TFL(i,k,1)  = j;
            TFL(i,k,2)  = (i-
            1)*d; k = k+1;
       end
    en
    d

    TFR = zeros(n-1,round((A-BZ)/2/mh_spacing)+1,2); % create an array
 to hold the locations of the right myosin heads
    % fill in array for myosin
    heads for i = 1:n-1
        k = 1;
        for j = (L+BZ)/2 + x*i:mh_spacing:(L+A)/2  + x*i
            TFR(i,k,1)  = j;
            TFR(i,k,2)  = (i-
            1)*d; k = k+1;
       end
    en
    d

    tfl = zeros(3,n); % create an array to hold the locations of the
 left thin filaments
    % fill in array for the thin
    filaments for i = 1:n
        tfl(1,i)  = (i-1)*x;
        tfl(2,i)  = I/2 + (i-
        1)*x; tfl(3,i)  = (i-
        1)*d;
    end

    tfr = zeros(3,n); % create an array to hold the locations of the
 right thin filaments
    % fill in array for the thin
    filaments for i = 1:n
```

```
        tfr(1,i) = L-
        I/2+i*x; tfr(2,i) =
        L+i*x; tfr(3,i) =
        (i-1)*d;
    end

    % compare the arrays to calculate the force
    Fsumn = zeros(1,n); % create an empty array to count the force
produced by each filament set

    for i = 1:n-1 % for each filament
        for k = 1:round((A-BZ)/2/mh_spacing)+1  % along all possible
            positions if (tfl(1,i) <= TFL(i,k,1)) && (TFL(i,k,1) <= tfl(2,i))
                                                                    % if
            the
left myosin head overlaps with the left thin filament
                if (tfr(1,i) <= TFL(i,k,1)) && (TFL(i,k,1) <= tfr(2,i)) %
if they left myosin head overlaps with the right thin filament
                    Fsumn(i) = Fsumn(i); % keep the force the same
because the thin filaments are interfering with each other
                else
                    Fsumn(i) = Fsumn(i) + 1; % if the thin filaments do
not overlap and there is a left myosin head, add one to the force.
                end
            end

            if (tfl(1,i+1) <= TFL(i,k,1)) && (TFL(i,k,1) <= tfl(2,i+1)) %
 check the thin filament on the other side of the left myosin head
                if (tfr(1,i+1) <= TFL(i,k,1)) && (TFL(i,k,1) <= tfr(2,i+1))
                    Fsumn(i) = Fsumn(i);
                else
                     Fsumn(i) = Fsumn(i) + 1;
                end
            end



            if (tfr(1,i) <= TFR(i,k,1)) && (TFR(i,k,1) <= tfr(2,i)) %do the
same for the right myosin heads
                if (tfl(1,i) <= TFR(i,k,1)) && (TFR(i,k,1) <= tfl(2,i))
                    Fsumn(i) = Fsumn(i);
                else
                    Fsumn(i) = Fsumn(i) + 1;
                end
            end

            if (tfr(1,i+1) <= TFR(i,k,1)) && (TFR(i,k,1) <= tfr(2,i+1))
                if (tfl(1,i+1) <= TFR(i,k,1)) && (TFR(i,k,1) <= tfl(2,i+1))
                    Fsumn(i) = Fsumn(i);
```

```
                else
                    Fsumn(i) = Fsumn(i) + 1;
                end
            end

        end

    end
    % store the length and total force in the LF array
    LF(l,1) = L;
    LF(l,2) = sum(Fsumn);



    % create/update the animation if called for
    if animate
        if isempty(h1) == false % delete graphics from the previous
            delete(h1);
            delete(h2);
            delete(h3);
            delete(h4);
            delete(h5);
        end

        % plot new components in the bottom panel
        subplot(2,1,1);
        hold on

        h1 = plot(TFL(1:n-1,1:round((A-BZ)/2/mh_spacing)+1,1),TFL(1:n-
1,1:round((A-BZ)/2/mh_spacing)+1,2),'g*');
        h2 = plot(TFR(1:n-1,1:round((A-BZ)/2/mh_spacing)+1,1),TFR(1:n-
1,1:round((A-BZ)/2/mh_spacing)+1,2),'g*');
        q = tfl(1:2,1:n);  w =
        tfl(3,1:n);  w(2,:) =
        tfl(3,1:n);  h3 =
        plot(q,w);



        r = tfr(1:2,1:n);  s =
        tfr(3,1:n);  s(2,:) =
        tfr(3,1:n);  h4 =
        plot(r,s);

        axis([0 A+2*I 0 h_initial]);
```

```
        % Adjust the length tension curve for P0 and L0
        [m,q] = size(LF);
        maxForce = max(LF(1:m,2));
        LTcurve(1:m,2)  = LF(1:m,2)/maxForce;



        [r,c] = find(LTcurve == 1);
        [x,y] = size(r);
        L0 = sum(r(1:x))/x;


        LTcurve(1:m,1)  = LF(1:m,1)/LF(round(L0),1);

        % plot new components in bottom panel
        subplot(2,1,2);
        hold on
        h5 = plot(LTcurve(1:m,1),LTcurve(1:m,2),'g*');
        axis([0 4 0 1])

        % add frame to the movie if we're creating one
        if exist('moviename','var')
            % Write each frame to the file
            currFrame = getframe(gcf);
            writeVideo(mov,currFrame);
        end
    else
        % Adjust the length tension curve for P0 and L0
        [m,q] = size(LF);
        maxForce = max(LF(1:m,2));
        LTcurve(1:m,2)  = LF(1:m,2)/maxForce;



        [r,c] = find(LTcurve == 1);
        [x,y] = size(r);
        L0 = sum(r(1:x))/x;


       LTcurve(1:m,1)  = LF(1:m,1)/LF(round(L0),1);
    en
    d


    pause(.01) % slight pause so the figure animation gets displayed

    if LF(l,2) == 0 % if the force is 0, stop the program
        break
    end
    l = l+1;

end
```

```
% close the movie if we created one
if exist('moviename','var')
    close(mov);
end




end
```

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