SIMM Motion Module
Supplementary Information
On Marker Sets and Joint Centers

This guide describes the markers used by the Motion Module and C3D Module in SIMM to load each Mocap Model, calculate joint center locations, scale the model to fit the subject, and import recorded motions. For more details on how the Motion Module processes the marker data and the model, see Chapter 5 of the SIMM User Guide. For a tutorial of the Motion Module, click on Help -> SIMM Tutorials -> Motion Module Demo in the SIMM menu bar. This document focuses on the names and locations of the markers, and how joint centers are calculated from the marker locations in the static pose.

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1. Definitions

static trial
a TRC, TRB, or C3D file of a motion capture subject in a static pose, usually the "T" or "scarecrow" pose

motion trial
a TRC, TRB, or C3D file of a subject performing an activity, such as walking or throwing

Mocap Model
a SIMM musculoskeletal model that can be loaded into SIMM, scaled to fit a subject using a static trial, and used to animate motion trials of that subject. The primary model is a full-body model with lower-extremity muscles, but others are available as well.

critical marker
a marker that is required in the static trial, and which must be placed in a specific location on the subject, according to instructions in the OrthoTrak manual. The coordinates of the marker in the static trial are used to determine joint centers and body segment lengths.

semi-critical marker
a marker that is optional in the static trial, but if used, must be placed in a specific location on the subject, according to instructions in the OrthoTrak manual. The coordinates of the marker in the static trial are used to improve the joint center calculations.

optional marker
a marker that is optional in the static trial, and whose placement on the subject does not need to be in a specific location

fixed marker
an optional marker whose X, Y, Z offsets are not automatically calculated when the static trial is processed. Rather, the offsets in the marker definition in the Mocap Model file are used to position the marker on the model (these offsets are scaled with the body segment, however).

2. Mocap Models

The Motion Module comes with four different Mocap Models for you to choose from. Each of them contains parameters that turn on and off different portions of the model, depending on which of the critical markers are present in the static trial. When you load a Model Model with a static trial, the Motion Module reads the list of markers from the trial and sets the values of the model parameters so that the appropriate portions are included. For example, if the critical markers on the right hand are present, then the degrees of freedom in the fingers are activated. If they are not present, the hand is modeled as one rigid body segment, with movement only at the wrist.

The Mocap Model that you will most likely want to use is *mocap.jnt*. This is a model of a full body, with lower extremity muscles and [optionally] movable fingers in each hand. There is also a right arm model and a left arm model (*rightArm.jnt* and *leftArm.jnt*). These should be used if you want to capture motion of one arm without any torso or pelvis markers. Lastly, *mocap3D.jnt* is similar to *mocap.jnt*, but it includes 3D muscle surfaces for 18 key lower extremity muscles, rather than the lines of action for all 86 muscles. These muscle shapes look more realistic, but they do not have force-generating parameters, so you cannot calculate the lengths or forces in these muscles during the recorded motion.

The table below shows the available combinations of model components. To determine which Mocap Model you should use, find the row that best describes the model you want, then locate the filename in the last column. All of these files are located in *SIMM\Resources\mocap*. Once you have determined which one to use, you can either set the MOCAP_MODEL preference in *SIMM\Resources\preferences.txt* to that file, or choose that file in the import dialog box when loading the static trial.

lower extremity	upper extremity	movable fingers	muscles	file name
yes	yes	yes	legs only	mocap.jnt
yes	yes	no	legs only	mocap.jnt
yes	no	no	legs only	mocap.jnt
no	yes	yes	none	mocap.jnt
no	yes	no	none	mocap.jnt
no	right arm only	yes	none	rightArm.jnt
no	right arm only	no	none	rightArm.jnt
no	left arm only	yes	none	leftArm.jnt
no	left arm only	no	none	leftArm.jnt
yes	yes	yes	legs only, 3D	mocap3D.jnt
yes	yes	no	legs only, 3D	mocap3D.jnt
yes	no	no	legs only, 3D	mocap3D.jnt

It is important to note that *the critical and semi-critical labels for markers are relevant only for the static trial. For motion trials, all markers are optional.* That is, after recording the static trial, you can

remove any of the markers from the subject before recording motion trials. Generally, however, you will want to keep all of the markers on the subject for the motion trials, with the possible exception of the medial joint markers. Also, once the static trial has been recorded, you must be careful not to move any of the markers on the subject (except for removing them completely). SIMM uses the static trial to calculate the coordinates of each marker relative to its body segment, so if you move a marker or add additional markers, you must re-record the static trial and re-load the Mocap Model.

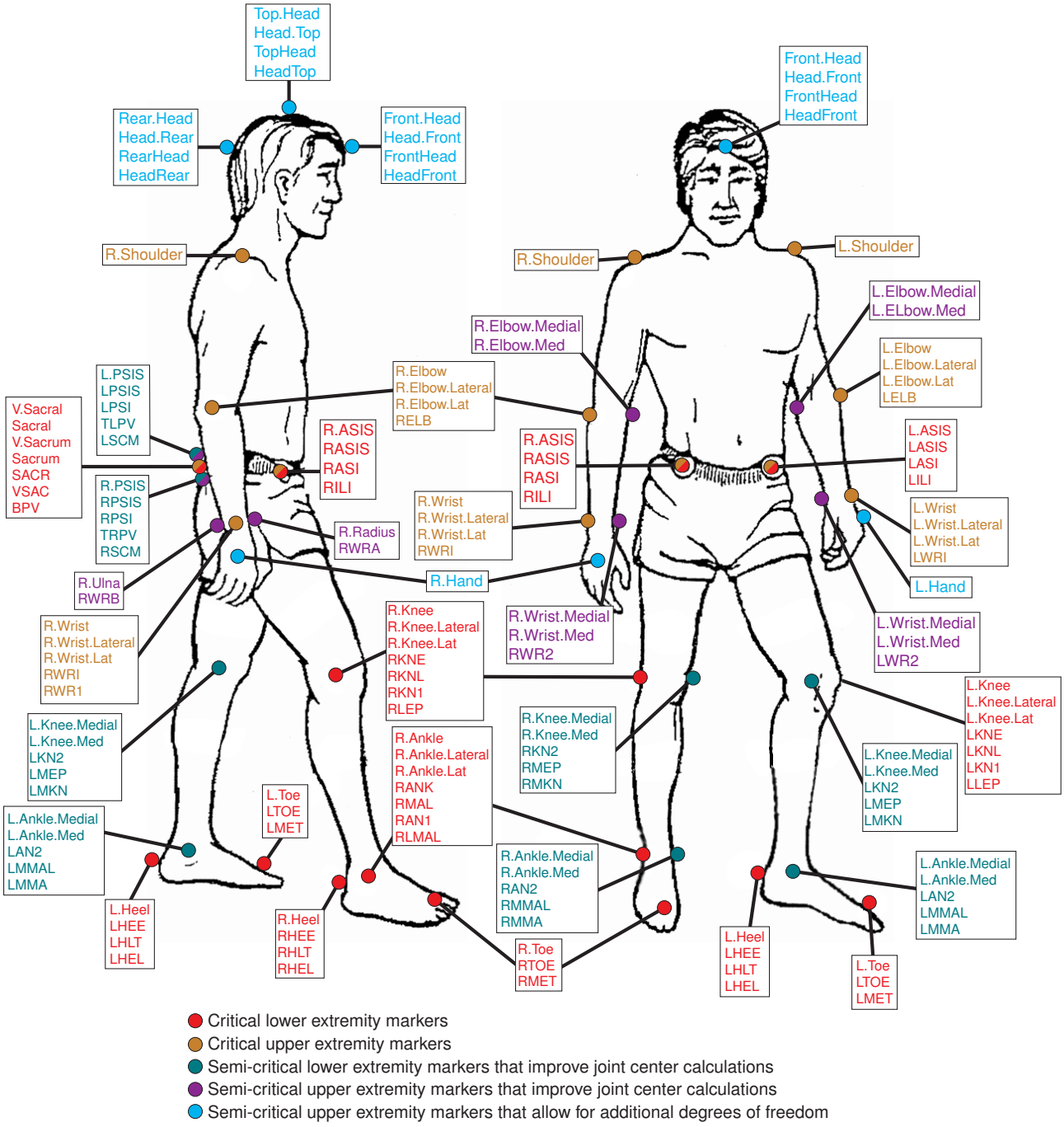
All of the markers described in this document are already part of the primary Mocap Model, located in *SIMM\Resources\mocap\mocap.jnt*. To use any of them, you do not need to make any changes to the file; just place the markers on the appropriate locations on the subject, and make sure the marker names in the static trial match the names shown in the figures below. Many of the markers can have one of several names, as listed in the box pointing to each marker in the figures. These names are case-insensitive, and may contain spaces.

If you want to add markers to the Mocap Model, you can do so with the Marker Editor in SIMM. This tool allows you to create new markers, attach them to the appropriate body segments, and specify their X,Y, Z offsets. The exact values of the offsets are not important; they are used only for display of the marker while creating it. The offsets will be overwritten with values calculated by the Motion Module when the static trial is processed and the model is scaled to fit the subject. This process is described in more detail in Chapter 5 of the SIMM User Guide, but here is a brief summary. After loading the static trial, the Motion Module places all of the critical markers that are in the trial on the Mocap Model in their corresponding locations. The Mocap Model is then scaled to match the subject, and then a least-squares optimization fits the model within the cloud of static trial markers, considering only the critical markers. This positions the model within the marker cloud so that the Motion Module can then directly calculate the offsets from the optional markers to the model segments to which they are attached. If you do not want the offsets for a marker to be calculated in this manner, then you must turn on the "fixed" button for that marker in the Marker Editor, and enter accurate X, Y, Z offsets into the number fields. This tells the Motion Module to scale the marker's offsets when the model is scaled, but not to recalculate their values as it does for the other optional markers.

Note on adding markers: You can create new markers using the Marker Editor, and then save the model by writing out a joint file, but you should not replace the original model file (*e.g., SIMM\Resources\mocap\mocap.jnt*) with this new file. This is because the model file contains many comments and special parameters that enable SIMM to automatically modify it for a particular static trial, as described above. However, when this file is loaded into SIMM and then written back out, these comments and parameters are lost. Thus after saving your new joint file, you should use a text editor to copy the new marker definitions from the file and paste them into the existing model file.

3. Critical Markers

Shown below are the critical and semi-critical markers for upper body and lower body motion recording. If any of the lower body critical markers are missing from the static trial, the legs will not be loaded with the Mocap Model. Similarly, if any of the upper body critical markers are missing from the static trial, the torso, head, and arms will not be loaded. Note that the pelvis markers are critical for both upper and lower body motion recording. If any of these markers are missing, the Motion Module will print an error and not load the Mocap. The head and hand markers are semi-critical. If used, they allow the Motion Module to track motion at the neck and wrist. If not used, these joints will remain fixed during animation of motion trials in SIMM.



For some portions of the body, SIMM supports alternative critical marker sets for use with the Mocap Model. For example, the sacral marker can be replaced with two PSIS markers, and the lateral wrist marker can be replaced with the radius marker. It is thus difficult to display in a single picture of the body the complete set of markers that are required. Sections 3.2 through 3.7 contain descriptions of the critical and semi-critical marker sets for each portion of the body.

3.1 Critical Marker Names

The descriptions of critical and semi-critical markers in the following sections list the acceptable names for each marker. These are the names that are built into SIMM; if you use any of these *case-insensitive* names for a marker, SIMM will automatically recognize it as the appropriate critical marker. If you want to use a different name for a certain marker, you must define a mapping between that name and the marker in SIMM. These mappings are defined in *importVariables.txt*, which can be put in the folder with your motion capture data, or in *SIMM\Resources\mocap\misc*. Please see Section 5.4.1 of the SIMM User Guide for more information on this file.

To use a custom name for a critical marker, you must do two things. First, you must add a marker with that name to the appropriate body segment in your model file. Second, you must add a mapping to *importVariables.txt* to tell SIMM about the new name. The format of the mapping is: the name of the new marker, followed by a tab, followed by the word *marker*, followed by the keyword identifying the SIMM critical marker. Marker names can contain spaces, so it is important to put a tab after the name to indicate the end. Example mappings are shown below, along with the keywords for each critical marker in SIMM.

```
my_sacral           marker      VSacral
my_Rasis            marker      RASIS
my_Lasis            marker      LASIS
my_psis             marker      RPSIS
my_lpsis            marker      LPSIS
my Rknee            marker      RKneeLat
my Lknee            marker      LKneeLat
my_rankle           marker      RAnkleLat
my_lankle           marker      LAnkleLat
my rheel            marker      RHeel
my lheel            marker      LHeel
MY_rtoe             marker      RToe
MY_ltoe             marker      LToe
my_rtroc            marker      RGreaterTroc
my_ltroc            marker      LGreaterTroc
my.rknee_med        marker      RKneeMed
my.lknee_med        marker      LKneeMed
my_rank_med         marker      RAnkleMed
my_lank_med         marker      LAnkleMed
my rshou            marker      RShoulder
my lshou            marker      LShoulder
my_relbow           marker      RElbowLat
my_lelbow           marker      LElbowLat
my.rwrist           marker      RWristLat
my.lwrist           marker      LWristLat
my_rwrist_f         marker      RWristFront
my_lwrist_f         marker      LWristFront
my_relb_med         marker      RElbowMed
my_lelb_med         marker      LElbowMed
```

```
my_rwrist_med        marker      RWristMed
my_lwrist_med        marker      LWristMed
MY_RWRIST_B          marker      RWristBack
MY_LRWIST_B          marker      LWristBack
my_headrear          marker      HeadRear
my_headtop           marker      HeadTop
my_headfront         marker      HeadFront
my_headfront_r       marker      HeadFrontRight
my_headfront_l       marker      HeadFrontLeft
my_headback_r        marker      HeadBackRight
my_headback_l        marker      HeadBackLeft
my_rmidfing          marker      RMiddleFinger
my_lmidfing          marker      LMiddleFinger
my.rthumb            marker      RThumb
my.lthumb            marker      LThumb
```

3.2 Lower Body

The lower body portion of the Mocap Model will be loaded if the critical markers listed below are present in the static trial. The thigh, shank, and feet segments will each be scaled separately, based on measurements made from the static trial. Each of these segments will be scaled uniformly in the X, Y, and Z dimensions. The pelvis segment will be scaled independently in the X, Y, and Z dimensions. It is not possible to load only one leg of the Mocap Model.

critical markers:

1. **right ASIS**. acceptable names: R.ASIS RASIS RASI RILI
2. **left ASIS**. acceptable names: L.ASIS LASIS LASI LILI
3. **posterior pelvis**:
   a. **sacrum**. acceptable names: V.SACRAL V.SACRUM SACRAL SACRUM SACR VSAC BPV
   or
   b. **right PSIS**. acceptable names: R.PSIS RPSIS RPSI TRPV RSCM
   and
   left PSIS. acceptable names: L.PSIS LPSIS LPSI TLPV LSCM
4. **right lateral knee**. acceptable names: R.KNEE R.KNEE.LATERAL R.KNEE.LAT RKNE RKNL RKN1 RLEP
5. **left lateral knee**. acceptable names: L.KNEE L.KNEE.LATERAL L.KNEE.LAT LKNE LKNL LKN1 LLEP
6. **right lateral ankle**. acceptable names: R.ANKLE R.ANKLE.LATERAL R.ANKLE.LAT RANK RMAL RAN1 RLMAL
7. **left lateral ankle**. acceptable names: L.ANKLE L.ANKLE.LATERAL L.ANKLE.LAT LANK LMAL LAN1 LLMAL
8. **right heel**. acceptable names: R.HEEL RHEE RHLT RHEL
9. **left heel**. acceptable names: L.HEEL LHEE LHLT LHEL
10. **right toe**. acceptable names: R.TOE RTOE RMET
11. **left toe**. acceptable names: L.TOE LTOE LMET

semi-critical markers:

1. **right medial knee**. acceptable names: R.KNEE.MEDIAL R.KNEE.MED RKN2 RMEP RMKN
2. **left medial knee**. acceptable names: L.KNEE.MEDIAL L.KNEE.MED LKN2 LMEP LMKN
3. **right medial ankle**. acceptable names: R.ANKLE.MEDIAL R.ANKLE.MED RAN2 RMMAL RMMA
4. **left medial ankle**. acceptable names: L.ANKLE.MEDIAL L.ANKLE.MED LAN2 LMMAL LMMA

Placement of Lower Body Markers

right ASIS: directly over the right anterior superior iliac spine

left ASIS: directly over the left anterior superior iliac spine

right PSIS: directly over the right posterior superior iliac spine

left ASIS: directly over the left posterior superior iliac spine

sacrum: midway between the left and right posterior superior iliac spines

For a normal subject standing in a normal position, all of the pelvis markers should be in the same horizontal plane. In some subjects the ASIS markers cannot be placed directly anterior to the ASIS, due to clothing, body shape, or other obstructions. If these markers are placed away from the ASIS, you may need to adjust the hip center parameters accordingly (see Section 5.1), and also the PELVIS_SIZE parameter in the Mocap Model joint file (*e.g.*, mocap.jnt). The three numbers following the keyword PELVIS_SIZE are the X, Y, and Z sizes of the unscaled pelvis. For example, the Z value, 0.256, is the distance between the right and left ASIS markers in the unscaled model. If the pelvis marker placement causes the subject's pelvis to scale too large, increase the X, Y, and Z sizes proportionally. This effectively tells SIMM that the unscaled pelvis is larger than it is, so it will be scaled less to fit the subject. It is recommended that you modify the X, Y, and Z sizes by the same percentage, but you may want to use non-uniform scaling for some subjects.

right lateral knee: on the center of the lateral epicondyle of the right knee

left lateral knee: on the center of the lateral epicondyle of the left knee

right lateral ankle: on the center of the lateral malleolus of the right ankle

left lateral ankle: on the center of the lateral malleolus of the left ankle

right heel: on the center of the posterior aspect of the left calcaneous, at the same height above the plantar surface as the left toe marker

left heel: on the center of the posterior aspect of the right calcaneous, at the same height above the plantar surface as the right toe marker

right toe: directly above the distal end of the second metatarsal on the right foot, at the same height above the plantar surface as the right heel marker. The toe marker is meant to be fixed to the mid-foot, and should not move with the toes as they are flexed.

left toe: directly above the distal end of the second metatarsal on the left foot, at the same height above the plantar surface as the left heel marker. The toe marker is meant to be fixed to the mid-foot, and should not move with the toes as they are flexed.

right medial knee: on the center of the medial epicondyle of the right knee

left medial knee: on the center of the medial epicondyle of the left knee

right medial ankle: on the center of the medial malleolus of the right ankle

left medial ankle: on the center of the medial malleolus of the left ankle

3.3 Upper Body

The upper body portion of the Mocap Model will be loaded if the critical markers listed below are present in the static trial. The upper arm and lower arm segments will each be scaled separately, based on measurements made from the static trial. Each of these segments will be scaled uniformly in the X, Y, and Z dimensions. The torso segment will be scaled independently in two dimensions (the X is scaled the same as the Z). It is not possible to load the upper body with only one arm. To load only one arm (without the rest of the upper body), use the SIMM file rightArm.jnt or leftArm.jnt as the Mocap Model.

critical markers:

1. **right ASIS**. acceptable names: R.ASIS RASIS RASI RILI
2. **left ASIS**. acceptable names: L.ASIS LASIS LASI LILI
3. **posterior pelvis**:
    a. **sacrum**. acceptable names: V.SACRAL V.SACRUM SACRAL SACRUM SACR VSAC BPV
    or
    b. **right PSIS**. acceptable names: R.PSIS RPSIS RPSI TRPV RSCM
    and
    left PSIS. acceptable names: L.PSIS LPSIS LPSI TRPV LSCM
4. **right shoulder**. acceptable names: R.SHOULDER RSHO
5. **left shoulder**. acceptable names: L.SHOULDER LSHO
6. **right lateral elbow**. acceptable names: R.ELBOW R.ELBOW.LATERAL R.ELBOW.LAT RELB REL1
7. **left lateral elbow**. acceptable names: L.ELBOW L.ELBOW.LATERAL L.ELBOW.LAT LELB LEL1
8. **right wrist**:
    a. **lateral**. acceptable names: R.WRIST R.WRIST.LATERAL R.WRIST.LAT RWRI RWR1
    or
    b. **radius**. acceptable names: R.RADIUS RWRA
9. **left wrist**:
    a. **lateral**. acceptable names: L.WRIST L.WRIST.LATERAL L.WRIST.LAT LWRI LWR1
    or
    b. **radius**. acceptable names: L.RADIUS LWRA

semi-critical markers:

1. **right medial elbow**. acceptable names: R.ELBOW.MEDIAL R.ELBOW.MED REL2
2. **left medial elbow**. acceptable names: L.ELBOW.MEDIAL L.ELBOW.MED LEL2
3. **right wrist**:
    a. **medial**. acceptable names: R.WRIST.MEDIAL R.WRIST.MED RWR2
    or
    b. **ulna**. acceptable names: R.ULNA RWRB
4. **left wrist**:
    a. **medial**. acceptable names: L.WRIST.MEDIAL L.WRIST.MED LWR2
    or
    b. **ulna**. acceptable names: L.ULNA LWRB

Placement of Upper Body Markers

For proper placement of the pelvis markers, see Section 3.2.

right shoulder: directly above the right acromio-clavicular joint

left shoulder: directly above the left acromio-clavicular joint

right lateral elbow: on the lateral epicondyle (near proximal end of right radius), approximating the elbow flexion axis

left lateral elbow: on the lateral epicondyle (near proximal end of left radius), approximating the elbow flexion axis

right lateral wrist: on the "top" or "back" of the wrist, at the midpoint of the distal ends of the right radius and right ulna

left lateral wrist: on the "top" or "back" of the wrist, at the midpoint of the distal ends of the left radius and left ulna

right radius: on the "side" of the wrist, directly over the distal end of the right radius

left radius: on the "side" of the wrist, directly over the distal end of the left radius

right medial elbow: on the medial epicondyle (near proximal end of the right ulna), approximating the elbow flexion axis

left medial elbow: on the medial epicondyle (near proximal end of the left ulna), approximating the elbow flexion axis

right medial wrist: on the "bottom" of the wrist, at the midpoint of the distal ends of the right radius and right ulna

left medial wrist: on the "bottom" of the wrist, at the midpoint of the distal ends of the left radius and left ulna

right ulna: on the "side" of the wrist, directly over the distal end of the right ulna

left ulna: on the "side" of the wrist, directly over the distal end of the left ulna

The line between the lateral and medial markers should approximate the wrist deviation axis. The line between the radius and ulna markers should approximate the wrist flexion axis.

3.4 Right Arm

To load only the right arm, set the MOCAP_MODEL parameter in your SIMM preferences file to *rightArm.jnt*, or choose that file using the *Options…Choose Model Model* command in the SIMM menu bar. Then use the markers listed below. For information on proper placement of the right arm markers, see Section 3.3.

critical markers:

1. **right shoulder**. acceptable names: R.SHOULDER RSHO
2. **right lateral elbow**. acceptable names: R.ELBOW R.ELBOW.LATERAL R.ELBOW.LAT RELB REL1
3. **right wrist**:
    a. **lateral**. acceptable names: R.WRIST R.WRIST.LATERAL R.WRIST.LAT RWRI RWR1
    or
    b. **radius**. acceptable names: R.RADIUS RWRA

semi-critical markers:

1. **right medial elbow**. acceptable names: R.ELBOW.MEDIAL R.ELBOW.MED REL2
2. **right wrist**:
    a. **medial**. acceptable names: R.WRIST.MEDIAL R.WRIST.MED RWR2
    or
    b. **ulna**. acceptable names: R.ULNA RWRB

3.5 Left Arm

To load only the left arm, set the MOCAP_MODEL parameter in your SIMM preferences file to *leftArm.jnt*, or choose that file using the *Options…Choose Model Model* command in the SIMM menu bar. Then use the markers listed below. For information on proper placement of the left arm markers, see Section 3.3.

critical markers:

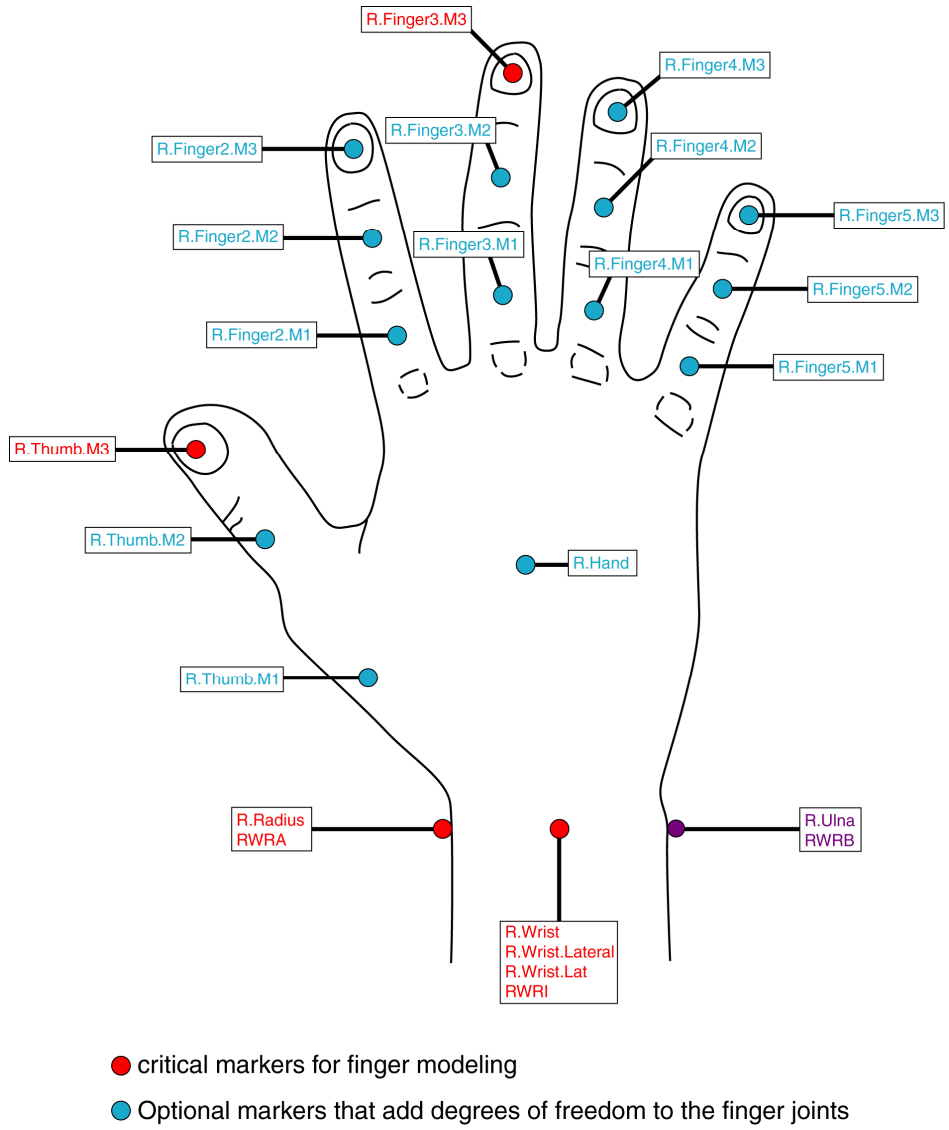
1. **left shoulder**. acceptable names: L.SHOULDER LSHO
2. **left lateral elbow**. acceptable names: L.ELBOW L.ELBOW.LATERAL L.ELBOW.LAT LELB LEL1
3. **left wrist**:
    a. **lateral**. acceptable names: L.WRIST L.WRIST.LATERAL L.WRIST.LAT LWRI LWR1
    or
    b. **radius**. acceptable names: L.RADIUS LWRA

semi-critical markers:

1. **left medial elbow**. acceptable names: L.ELBOW.MEDIAL L.ELBOW.MED LEL2
2. **left wrist**:
    a. **medial**. acceptable names: L.WRIST.MEDIAL L.WRIST.MED LWR2
    or
    b. **ulna**. acceptable names: L.ULNA LWRB

3.6 Hand

The markers shown below are used by the Motion Module to control the degrees of freedom in the hand. If the three critical markers are present in the static trial, the Motion Module will load a detailed model of the hand with three joints in each finger. By default, all of the finger joints are fixed. SIMM converts them into hinge joints as it detects the presence of markers to control the joints. For example, if R.Finger2.M1, R.Finger2.M2, and R.Finger2.M3 are all present, SIMM will create three hinge joints in the index finger, each with its own degree of freedom. If only R.Finger2.M1 is present, SIMM will create the proximal finger joint with a degree of freedom, and make the two distal joints dependent on the proximal one (so that all three joints will flex when the proximal one does). Any combination of the optional markers can be used to create a hand model with the desired degrees of freedom. All of the optional hand markers are defined as "fixed" in the model file. This means that the offsets specified in the file are used for solving motions (the Motion Module does not overwrite them), and thus you should place the markers on the subject according to how they are shown in the figure below.



3.6.1 Right Hand

The right hand will always be included when the right arm is loaded, even if there are no markers on the hand. The presence of critical markers controls how the hand is scaled and what degrees of freedom it has. The right hand will be scaled separately from the right lower arm if the three critical markers listed below are present in the static trial. The individual finger gencoords will be added to the model if the three critical hand markers and the appropriate finger markers are present in the static trial.

critical markers:

1. **right thumb**. acceptable names: R.THUMB R.THUMB.M3
2. **right middle finger**. acceptable names: R.MIDDLE.FINGER R.FINGER R.FINGER3.M3
3. **right wrist**:
    a. **lateral**. acceptable names: R.WRIST R.WRIST.LATERAL R.WRIST.LAT RWRI RWR1
    or
    b. **radius**. acceptable names: R.RADIUS RWRA

semi-critical markers:

1. **right wrist**:
    a. **medial**. acceptable names: R.WRIST.MEDIAL R.WRIST.MED RWR2
    or
    b. **ulna**. acceptable names: R.ULNA RWRB

3.6.2 Left Hand

The left hand will always be included when the left arm is loaded, even if there are no markers on the hand. The presence of critical markers controls how the hand is scaled and what degrees of freedom it has. The left hand will be scaled separately from the left lower arm if the three critical markers listed below are present in the static trial. The individual finger gencoords will be added to the model if the three critical hand markers and the appropriate finger markers are present in the static trial.

critical markers:

1. **left thumb**. acceptable names: L.THUMB L.THUMB.M3
2. **left middle finger**. acceptable names: L.MIDDLE.FINGER L.FINGER L.FINGER3.M3
3. **left wrist**:
    a. **lateral**. acceptable names: L.WRIST L.WRIST.LATERAL L.WRIST.LAT LWRI LWR1
    or
    b. **radius**. acceptable names: L.RADIUS LWRA

semi-critical markers:

1. **left wrist**:
    a. **medial**. acceptable names: L.WRIST.MEDIAL L.WRIST.MED LWR2
    or
    b. **ulna**. acceptable names: L.ULNA LWRB

Placement of Hand Markers

For proper placement of the markers on the wrist, see Section 3.2

R.Hand: middle of the back (superior aspect) of the hand

R.Thumb.M1: middle of the superior aspect of the first metacarpal

R.Thumb.M2: middle of the superior aspect of the first proximal phalange

R.Thumb.M3: middle of the nail on the thumb

R.Finger2.M1: middle of the superior aspect of the second proximal phalange

R.Finger2.M2: middle of the superior aspect of the second middle phalange

R.Finger2.M3: middle of the nail on the index finger

R.Finger3.M1: middle of the superior aspect of the third proximal phalange

R.Finger3.M2: middle of the superior aspect of the third middle phalange

R.Finger3.M3: middle of the nail on the middle finger

R.Finger4.M1: middle of the superior aspect of the fourth proximal phalange

R.Finger4.M2: middle of the superior aspect of the fourth middle phalange

R.Finger4.M3: middle of the nail on the ring finger

R.Finger5.M1: middle of the superior aspect of the fifth proximal phalange

R.Finger5.M2: middle of the superior aspect of the fifth middle phalange

R.Finger5.M3: middle of the nail on the pinky finger

3.7 Head

The head will always be included when the upper body is loaded, and the neck will contain three degrees of freedom. If the critical markers listed below are present in the static trial, the head will be scaled separately from the torso. Otherwise, the head will be scaled uniformly by the scale factor used for the Y (height) of the torso. If no markers (critical or optional) are included on the head in the static trial, then the degrees of freedom in the neck will remain fixed during imported motions.

critical markers:

1. **rear of head**. acceptable names: HEAD.REAR REAR.HEAD HEADREAR REARHEAD
2. **top of head**. acceptable names: HEAD.TOP TOP.HEAD HEADTOP TOPHEAD
3. **front of head**. acceptable names: HEAD.FRONT FRONT.HEAD HEADFRONT FRONTHEAD

Placement of Head Markers

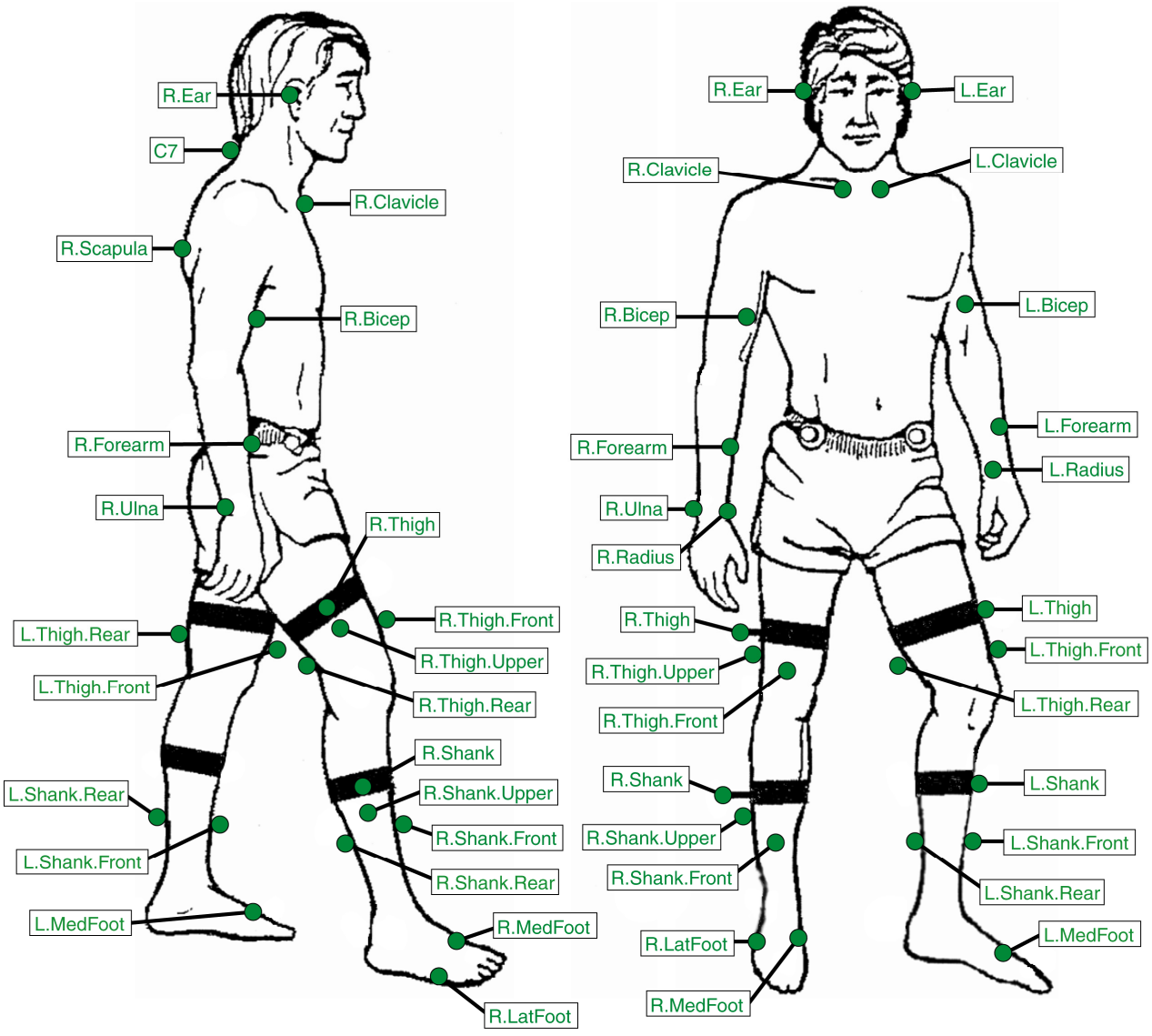
front of head: on the center of the forehead (midline of body), as close to the skull as possible

rear of head: on the back of the head and on the midline of the body, as close to the skull as possible. When the subject holds his/her head in a neutral position, the front and rear head markers should be in the same horizontal plane.

top of head: on the top of the head and on the midline of the body, midway between the front and read head markers.

4. Optional Markers

The markers shown below are optional. If any of these markers is in the static trial, its location on the corresponding body segment in the Mocap Model will automatically be determined after the model has been scaled using the critical markers (*i.e.*, these optional markers are not "fixed," so their X, Y, Z offsets in the model file will be overwritten when the model is loaded). These markers will then be used to help solve the frames of data in a motion trial.



The following optional markers are already defined in *mocap.jnt*. To use them, just put their exact names in your Cortex project:

Marker Name	SIMM Body Segment	Recommended Placement
R.Trochanter	pelvis	directly on top of the right greater trochanter, as determined by palpation
L.Trochanter	pelvis	directly on top of the left greater trochanter, as determined by palpation
Offset	thorax	anywhere on the back of the ribcage, except along the midline of the body
Sternum	thorax	anywhere on the sternum
T10	thorax	on the spinous process of the tenth thoracic vertebra
CLAV	thorax	at the jugular notch where the clavicles join the sternum
STRN	thorax	anywhere on the sternum
RBAK	thorax	anywhere on the back of the ribcage
C7	cerv7	on the spinous process of the seventh cervical vertebra
C7 Spinous Process	cerv7	on the spinous process of the seventh cervical vertebra
R.Ear	head	above the right ear
L.Ear	head	above the left ear
RBHD	head	on the right side of the back of the head
RFHD	head	over the right temple
LBHD	head	on the left side of the back of the head
LFHD	head	over the left temple
HEDO	head	anywhere on the head
HEDP	head	anywhere on the head
HEDA	head	anywhere on the head
HEDL	head	anywhere on the head
R.Clavicle	clavicle_r	anywhere on the right clavicle
L.Clavicle	clavicle_l	anywhere on the left clavicle
R.Scapula	scapula_r	anywhere on the right scapula
R.Scapula.Top	scapula _r	on the angulus acromialis of the right scapula
R.Scapula.Bottom	scapula _r	on the angulus inferior of the right scapula
R.Angulus Acromialis	scapula _r	on the angulus acromialis of the right scapula
R.Trigonum Spinae	scapula _r	on the trigonum spinae of the right scapula
R.Angulus Inferior	scapula _r	on the angulus inferior of the right scapula
L.Scapula	scapula _l	anywhere on the left scapula
L.Scapula.Top	scapula _l	on the angulus acromialis of the left scapula
L.Scapula.Bottom	scapula _l	on the angulus inferior of the left scapula
L.Angulus Acromialis	scapula _l	on the angulus acromialis of the left scapula
L.Trigonum Spinae	scapula _l	on the trigonum spinae of the left scapula
L.Angulus Inferior	scapula _l	on the angulus inferior of the left scapula
R.Bicep	humerus_r	on the anterior aspect of the right biceps muscle
R.Biceps.Lateral	humerus_r	on the lateral aspect of the right biceps muscle
L.Bicep	humerus_l	on the anterior aspect of the left biceps muscle
L.Biceps.Lateral	humerus_l	on the lateral aspect of the left biceps muscle
R.Forearm	ulna_r	anywhere on the ulnar side of the right forearm
L.Forearm	ulna_l	anywhere on the ulnar side of the left forearm

R.Thigh	femur_r	anywhere on the right thigh, usually on the lateral aspect
R.Thigh.Upper	femur_r	usually part of the right thigh marker array used by the Cleveland Clinic marker set
R.Thigh.Front	femur _r	usually part of the right thigh marker array used by the Cleveland Clinic marker set
R.Thigh.Rear	femur _r	usually part of the right thigh marker array used by the Cleveland Clinic marker set
RTHI	femur _r	anywhere on the right thigh, usually on the lateral aspect
L.Thigh	femur _l	anywhere on the left thigh, usually on the lateral aspect
L.Thigh.Upper	femur _l	usually part of the left thigh marker array used by the Cleveland Clinic marker set
L.Thigh.Front	femur _l	usually part of the left thigh marker array used by the Cleveland Clinic marker set
L.Thigh.Rear	femur _l	usually part of the left thigh marker array used by the Cleveland Clinic marker set
LTHI	femur _l	anywhere on the left thigh, usually on the lateral aspect
R.Shank	tibia_r	anywhere on the right shank, usually on the lateral aspect
R.Shank.Upper	tibia _r	usually part of the right shank marker array used by the Cleveland Clinic marker set
R.Shank.Front	tibia _r	usually part of the right shank marker array used by the Cleveland Clinic marker set
R.Shank.Rear	tibia _r	usually part of the right shank marker array used by the Cleveland Clinic marker set
RTIB	tibia _r	anywhere on the right shank, usually on the lateral aspect
L.Shank	tibia _l	anywhere on the left shank, usually on the lateral aspect
L.Shank.Upper	tibia _l	usually part of the left shank marker array used by the Cleveland Clinic marker set
L.Shank.Front	tibia _l	usually part of the left shank marker array used by the Cleveland Clinic marker set
L.Shank.Rear	tibia _l	usually part of the left shank marker array used by the Cleveland Clinic marker set
LTIB	tibia _l	anywhere on the left shank, usually on the lateral aspect
R.MedFoot	foot_r	on the first metatarsal of the right foot
R.LatFoot	foot _r	on the fifth metatarsal of the right foot
L.MedFoot	foot _l	on the first metatarsal of the left foot
L.LatFoot	foot _l	on the fifth metatarsal of the left foot

5. Joint Center Calculations

The Motion Module contains algorithms to calculate the centers of the hip, knee, ankle, shoulder, elbow, and wrist joints from marker positions in the static pose. These algorithms are similar to the ones in OrthoTrak, but have been enhanced to work when some markers or clinical measurements are missing. For the knee, ankle, elbow, and wrist, these algorithms contain several methods for locating the joint center when the medial marker is not used. These methods make assumptions about the position of the body in the static pose, such as the legs being parallel to each other. In most cases these assumptions will be valid, and the joint calculations will be accurate. *However, it is always preferable to use medial markers to define joint centers.* This is because the software can simply calculate the midpoint of the lateral and medial markers, rather than using other markers to calculate reference frames and translation vectors.

It is important to note that joint centers are calculated by the Motion Module only to determine the lengths of body segments for scaling the Mocap Model to fit the subject. For example, once the hip center and knee center are found, the distance between them is defined as the thigh length. This length is compared to the thigh length in the unscaled Mocap Model in order to calculate a scale factor for the thigh. Once the scale factors for all the body segments have been calculated, the joint center information is no longer needed.

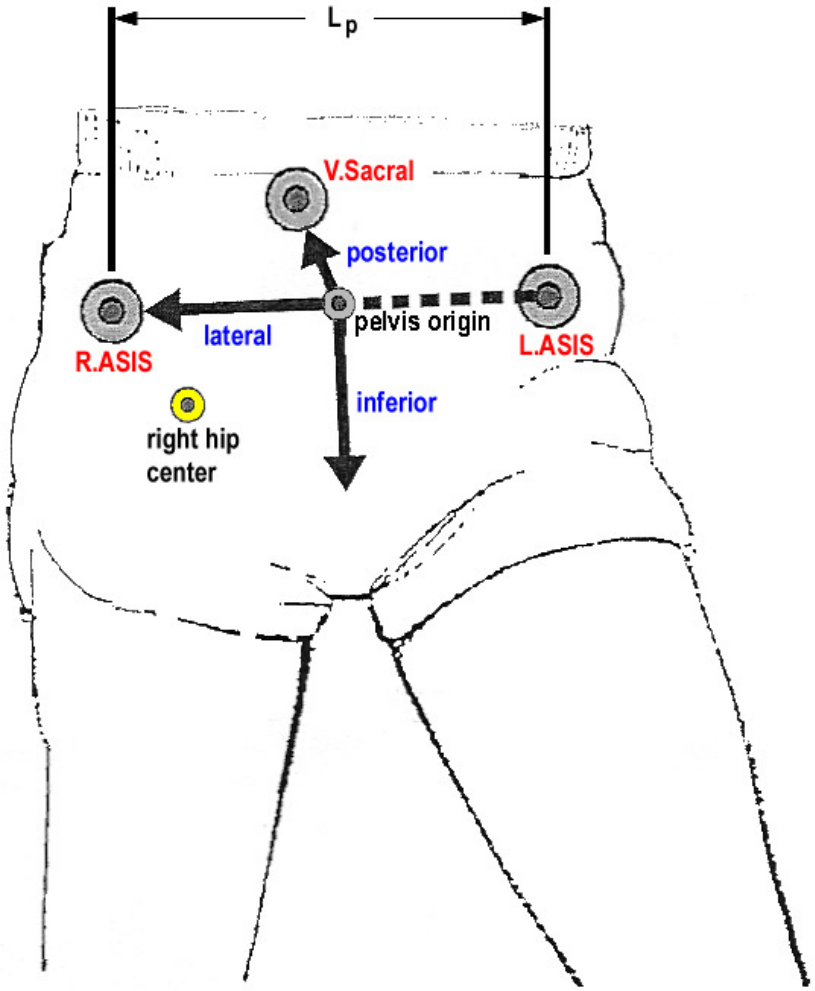
The joint center calculations are not used to define kinematics because the Mocap Model is a complete kinematic model of an average adult human, with body segments, muscles, degrees of freedom, and axes of rotation. This model is scaled segment-by-segment to fit the motion capture subject, but the joint kinematics are not modified for each subject. For example, the knee is a two degree-of-freedom joint model that includes the rolling of the femur on the tibial plateau during flexion, the screw-home effect at full extension, and varus-valgus rotation. The placement of the knee markers does not define the flexion axis or any other component of the knee joint; the placement only affects the sizes of the thigh and shank body segments. If you would like to modify any of the model's kinematics for a particular subject or for all subjects, you can do so by loading the model into SIMM or by editing the joint file (*e.g.*, mocap.jnt) with a text editor.

5.1 Hip Joint Center

The location of the hip joint center is determined from user-specified displacements from the origin of the pelvis coordinate system, which is located at the midpoint of the two ASIS markers. The displacements are specified as percentages of $\mathbf{L_p}$, the distance between the two ASIS markers. These lateral, inferior, and posterior displacement percentages are specified in *personal.dat*. The default values are:

Lateral: 32%
Inferior: 34%
Posterior: 22%

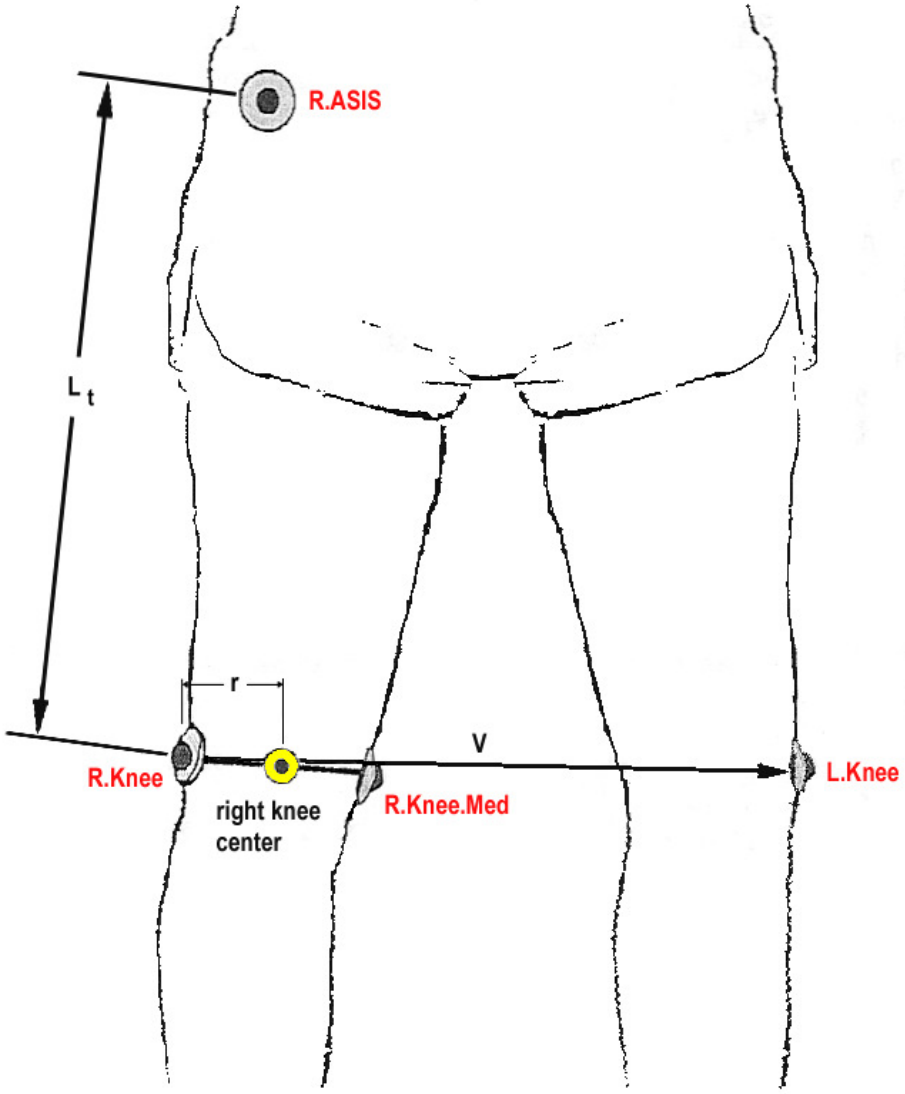
These default values were obtained from *Bell et al., Journal of Biomechanics, 23(6), 1990, pp. 617-21*. The posterior direction is defined as the vector from the pelvis origin to the sacral marker. The lateral direction is defined as the vector from the pelvis origin to the relevant ASIS marker (R.ASIS for the right hip joint lateral direction, L.ASIS for the left hip joint lateral direction). The inferior direction is perpendicular to the posterior and lateral directions. As described in Section 3.1, two PSIS markers may be used instead of the sacral marker. In this case, the midpoint of the two PSIS markers is used to define the posterior direction.



5.2 Knee Joint Center

To calculate the knee joint center, the lateral knee marker is required, and the medial knee marker is recommended. If the medial marker is missing, method 2 or 3 will be used to calculate the joint center. For best results with methods 2 and 3, the subject's legs should be parallel to each other.

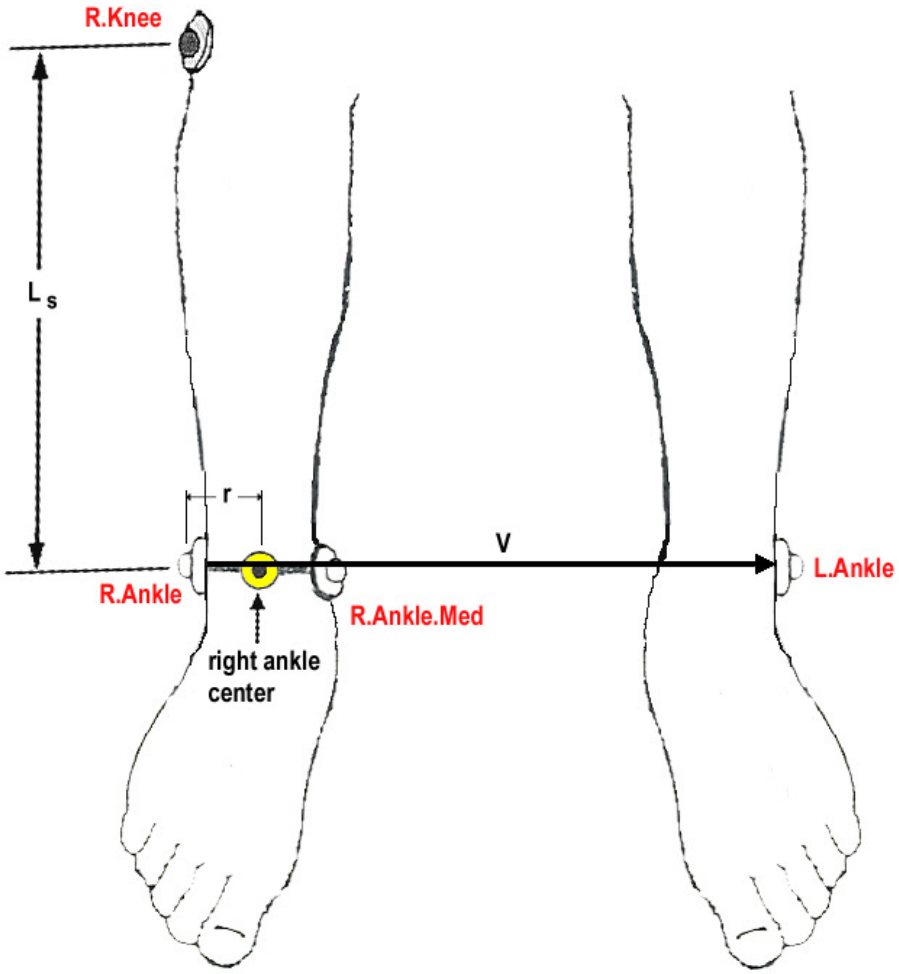
1. If the medial marker is present, the knee center is defined as the midpoint of the medial and lateral markers.
2. If the medial marker is missing but the knee diameter is specified in *personal.dat*, locate the knee center by moving half of the diameter (**r**) from the lateral marker along a vector **V**. **V** is the vector from the lateral marker to the other knee's lateral marker
3. If the medial marker is missing and the knee diameter is not specified, locate the knee center by moving a distance **r** from the lateral marker along a vector **V**. **r** is 10% of $\mathbf{L_t}$, the distance between the ASIS marker and the lateral knee marker. **V** is the vector from the lateral knee marker to the other knee's lateral marker.



5.3 Ankle Joint Center

To calculate the ankle joint center, the lateral ankle marker is required, and the medial ankle marker is recommended. If the medial marker is missing, method 2 or 3 will be used to calculate the joint center. For best results with methods 2 and 3, the subject's legs should be parallel to each other.

1. If the medial marker is present, the ankle center is defined as the midpoint of the medial and lateral markers.
2. If the medial marker is missing but the ankle diameter is specified in *personal.dat*, locate the ankle center by moving half of the diameter (**r**) from the lateral marker along a vector **V**. **V** is the vector from the lateral marker to the other ankle's lateral marker
3. If the medial marker is missing and the ankle diameter is not specified, locate the ankle center by moving a distance **r** from the lateral marker along a vector **V**. **r** is 10% of $\mathbf{L_s}$, the distance between the lateral knee marker and the lateral ankle marker. **V** is the vector from the lateral ankle marker to the other ankle's lateral marker.



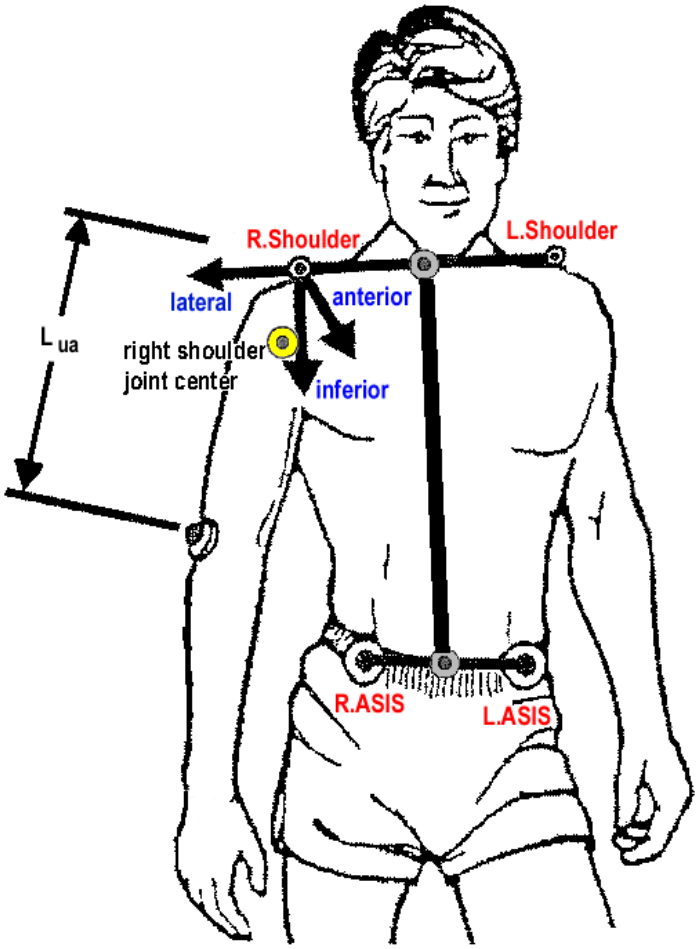
5.4 Shoulder Joint Center

The location of the shoulder joint center is determined from user-specified displacements from the shoulder marker. The displacements are specified as percentages of $\mathbf{L_{ua}}$, the distance between the shoulder marker and the lateral elbow marker. These lateral, inferior, and anterior displacement percentages are specified in *personal.dat*. The default values are:

Lateral: -2.5%
Inferior: 12.5%
Anterior: -1.25%

These default values were obtained by measuring the actual joint center offsets from the shoulder marker on the SIMM model of an average adult male. References describing the construction of this model are available at the top of the joint file. However, because there is much variability in the placement of the shoulder marker, these offsets may need to be changed for different subjects.

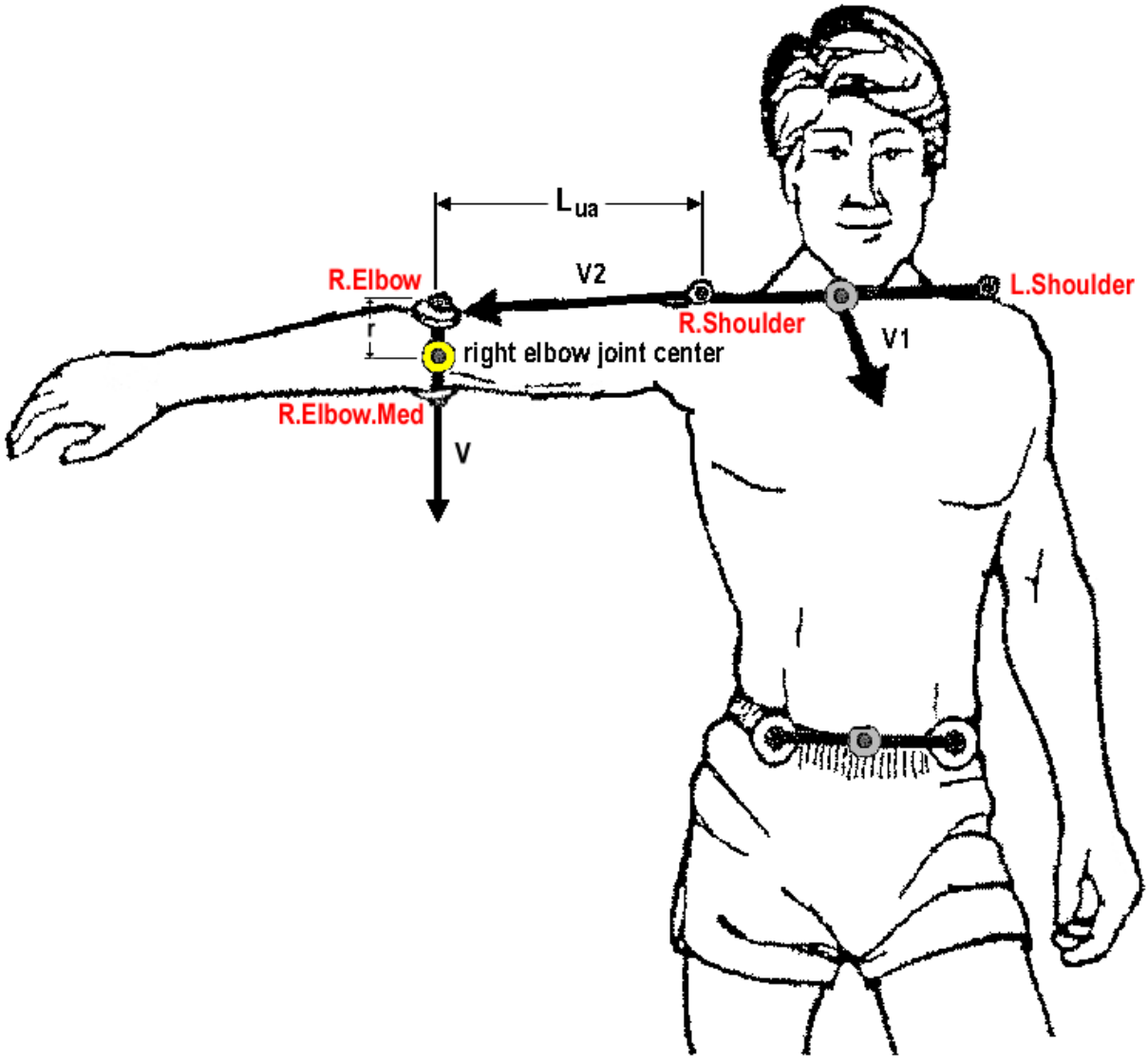
The anterior direction is the anterior axis of the trunk, which is defined as the cross product of the vector from the pelvis center to the shoulder marker midpoint and the vector from the left shoulder marker to the right shoulder marker. The lateral direction is defined as the vector from one shoulder marker to the other. The inferior direction is perpendicular to the anterior and lateral directions.



5.5 Elbow Joint Center

To calculate the elbow joint center, the lateral elbow marker is required, and the medial elbow marker is recommended. If the medial marker is missing, method 2 will be used to calculate the joint center. For best results with method 2, the subject's arms should be to the side (abducted or not) with the thumbs pointing forward.

1. If the medial marker is present, the elbow center is defined as the midpoint of the medial and lateral markers.
2. If the medial marker is missing, locate the elbow center by moving a distance **r** along a vector **V**. **r** is 14% of $\mathbf{L_{ua}}$, the distance between the shoulder marker and the lateral elbow marker. **V** is the cross product of **V1** and **V2**. **V1** is the anterior axis of the trunk, which is defined as the cross product of the vector from the pelvis center to the shoulder marker midpoint and the vector from the left shoulder marker to the right shoulder marker. **V2** is the vector from the shoulder marker to the lateral elbow marker.



5.6 Wrist Joint Center

It is recommended that two wrist markers be used to define the location of the wrist center. For the right wrist these two markers can be either R.Wrist and R.Wrist.Med, or R.Radius and R.Ulna. If only one marker is used, it must be R.Wrist. In this case, the subject's arms should be to the side (abducted or not) with the thumbs pointing forward. Here are the three methods available to calculate the right wrist joint center, in the order in which they are attempted. The methods for the left wrist are the same, but using the left wrist markers.

1. If R.Radius and R.Ulna are present, the wrist center is defined as the midpoint of those markers.
2. If R.Wrist and R.Wrist.Med are present, the wrist center is defined as the midpoint of those markers.
3. If only R.Wrist is present, locate the wrist center by moving a distance **r** from that marker along a vector **V**. **r** is 15% of $\mathbf{L_{la}}$, the distance between R.Elbow and R.Wrist. **V** is the cross product of **V1** and **V2**. **V1** is the anterior axis of the trunk, which is defined as the cross product of the vector from the pelvis center to the shoulder marker midpoint and the vector from L.Shoulder to R.Shoulder. **V2** is the vector from R.Elbow to R.Wrist.