Abdominal model

Segments in abdominal model

Five disks each attached to a vertebra using a spherical joint

Disk 1

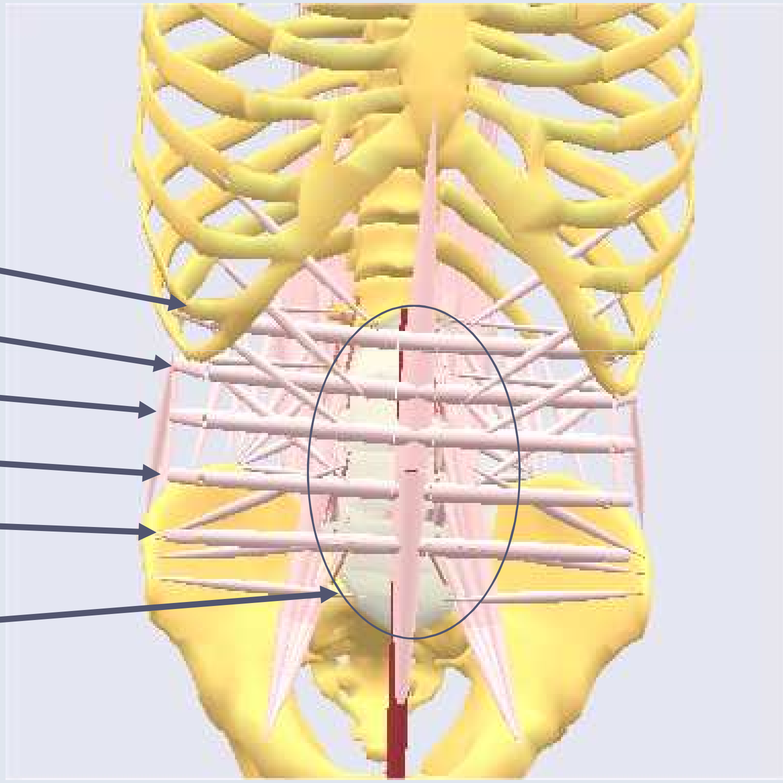
Disk 2

Disk 3

Disk 4

Disk 5

Buckle segment



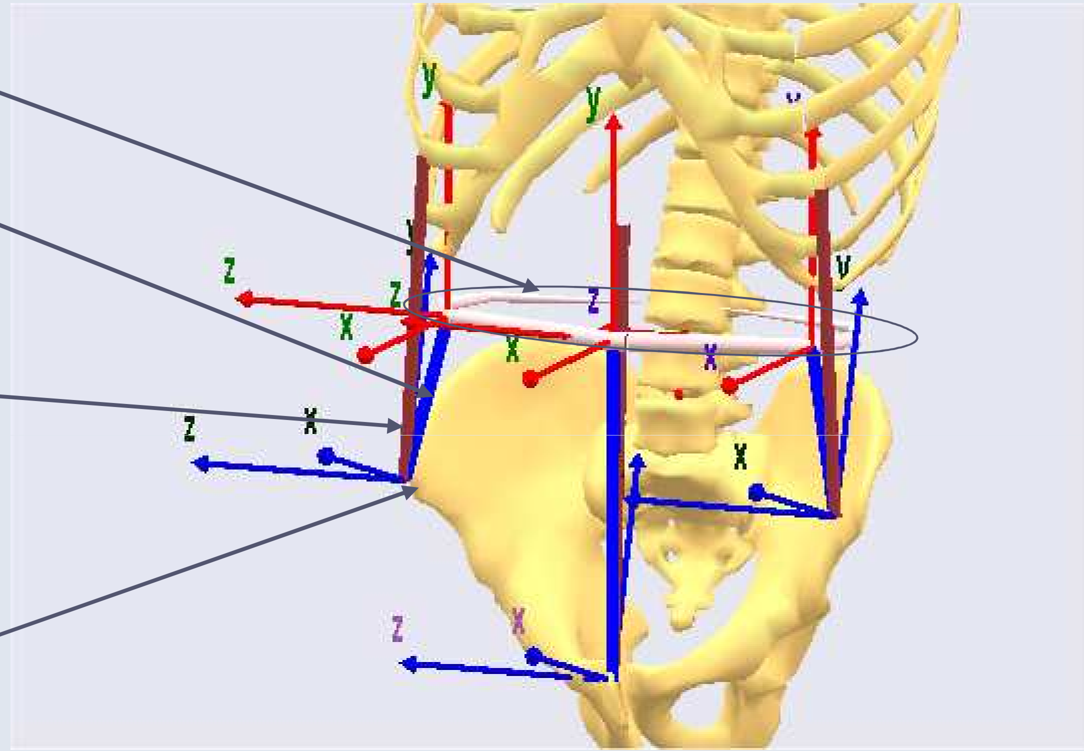
Kinematics of a disk – vertical movement

One of the five disks

Right hand side linear measure (blue line) from a point on the pelvis’ right hand side to the right hand side on the disc

Right hand side linear measure (red line) from point on pelvis right side to point on thorax right side

Reference coordinate systems for both the linear measures (blue coordinate system)



The point given by the red coordinate system on the right hand side of the disk is driven by a linear combination of the two linear measures shown above. Only the y coordinate is driven, a similar point on the left hand side of the disc the same way.
The short explanation: The height of the disk is driven on both sides

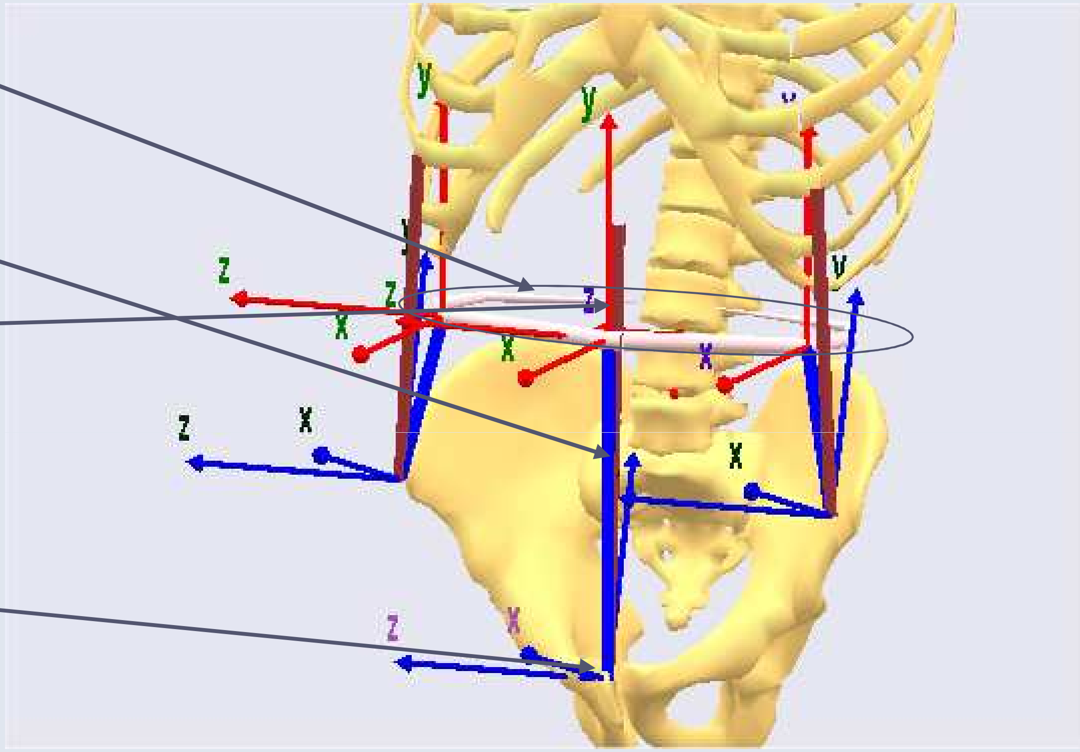
Kinematics of a disc – lateral movement

One of the five disks

Center linear measure (blue line) from center point on pelvis to center point on disk

Center linear measure (red line) from center point on pelvis to a point on thorax

Reference coordinate systems for both the linear measures (blue coordinate system)

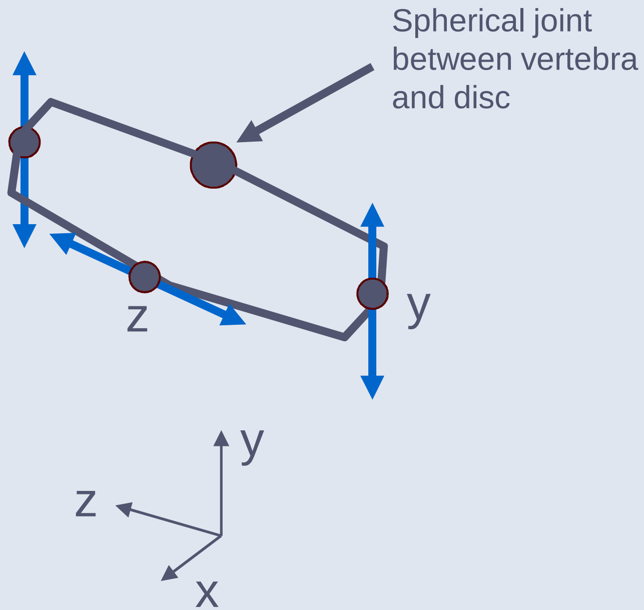


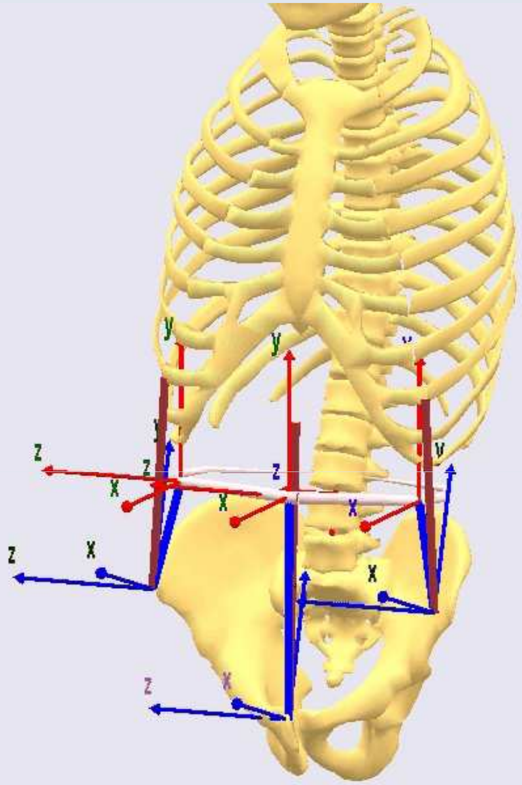
The point given by the red coordinate system at the center of the disc is driven by a linear combination of the two linear measures shown above. Only the z coordinate is driven.

The short explanation: The frontmost point on the disk is driven laterally.

Kinematical determinacy of a disk

Kinematic sketch of one of the disks





The three drivers shown on the previous two slides are shown as blue arrows. Together with the spherical joint the kinematics of the disc is now fully defined.

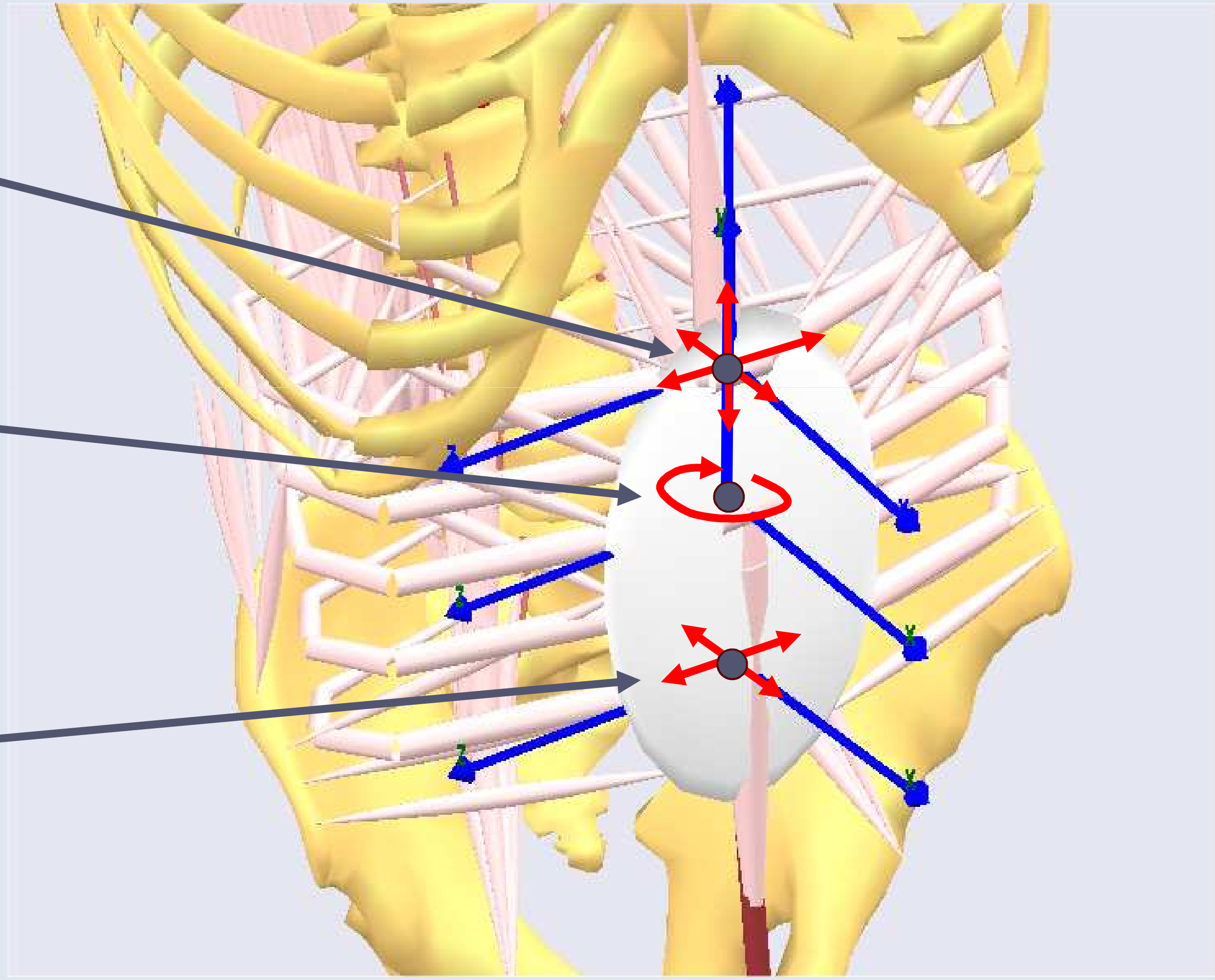
Kinematics of the buckle

The buckle is an assembly point for all the abdominal muscles from different directions

Spherical joint between disc1 and top of buckle

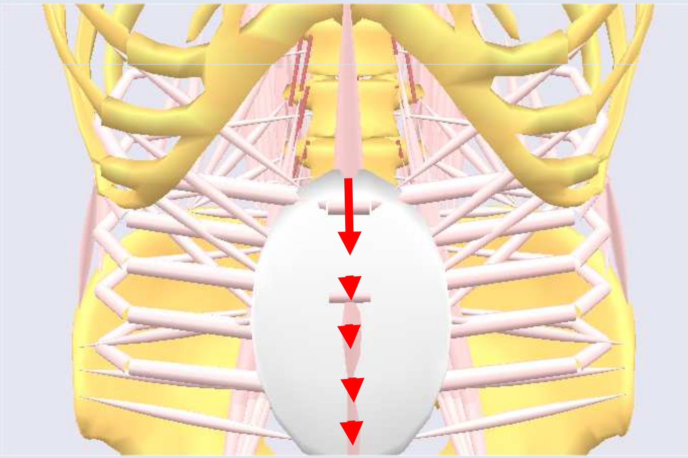
Rotation around y axis between buckle and disk3 driven to zero

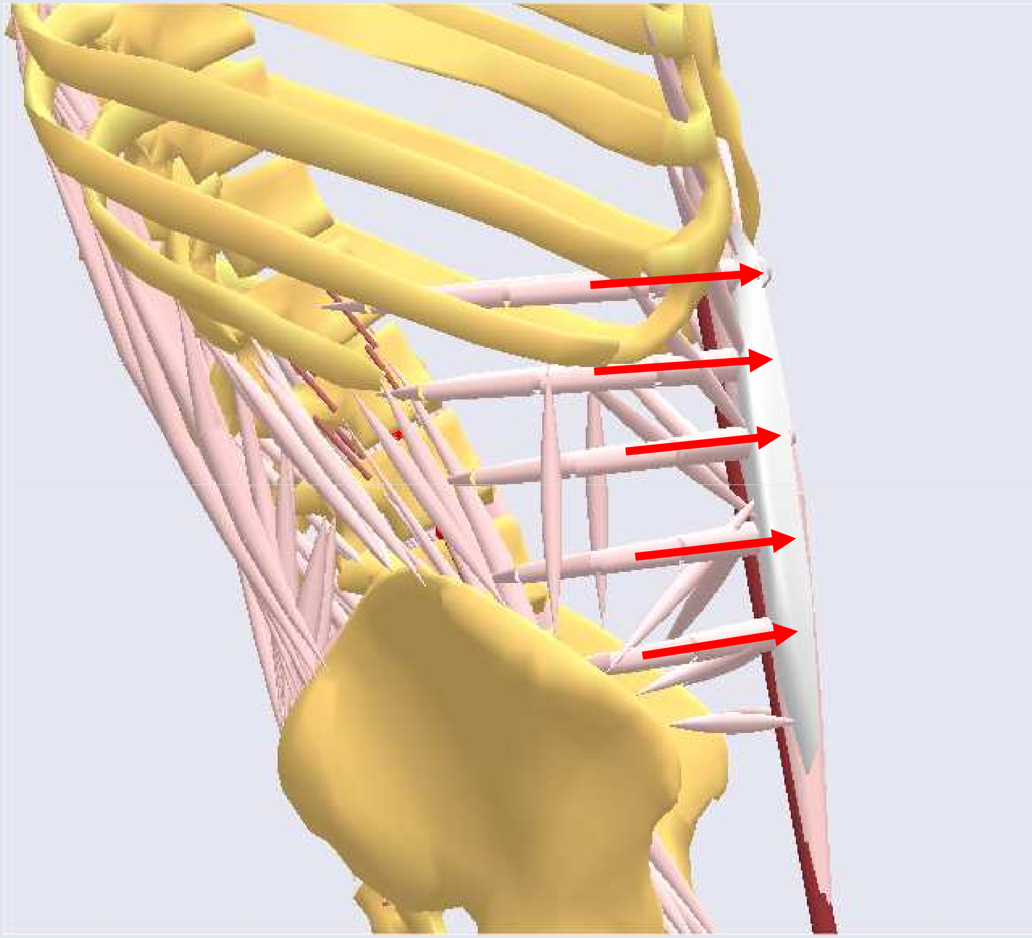
Linear measure between bottom of buckle and disk 5. x and z directions are driven to zero



Kinetics of the buckle

Five support force made as artificial pushing muscles (red arrows) act from each of the disks to the buckle. The support forces act in the plane of the disks.

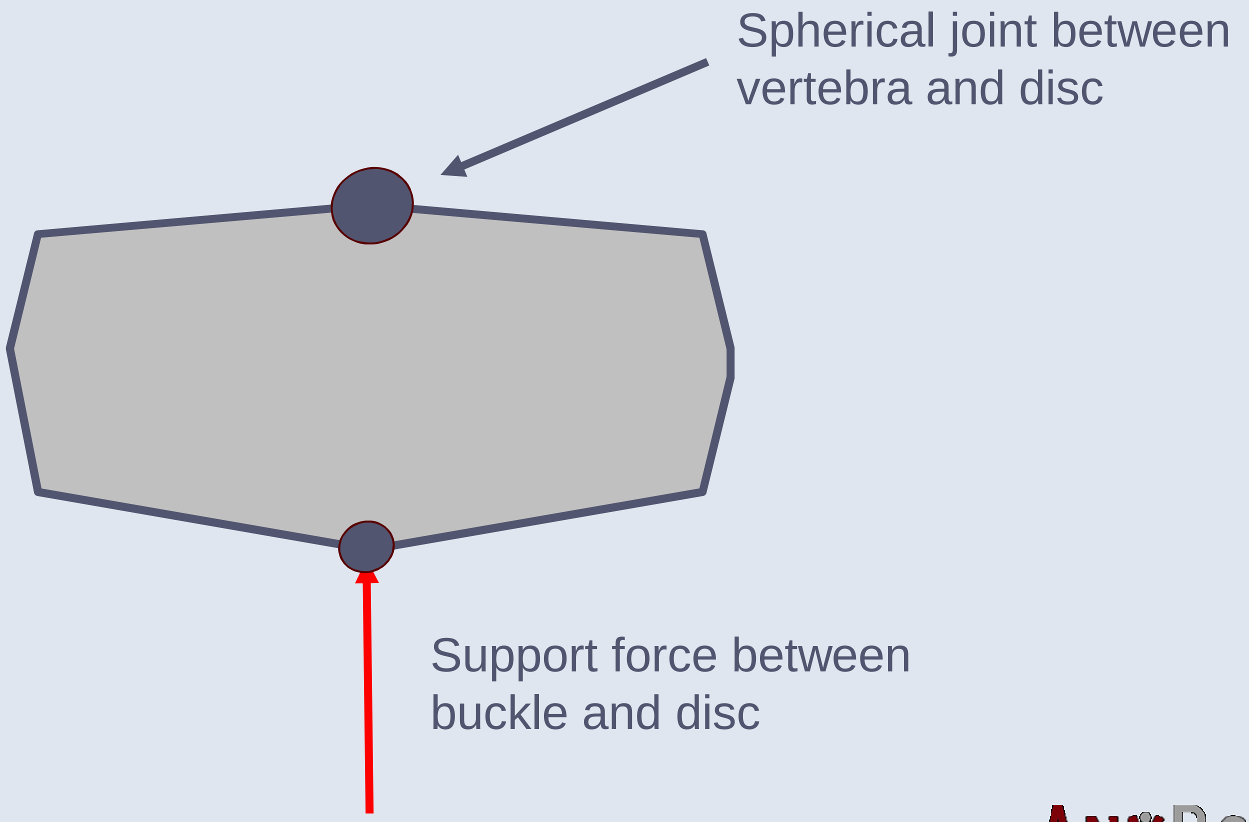




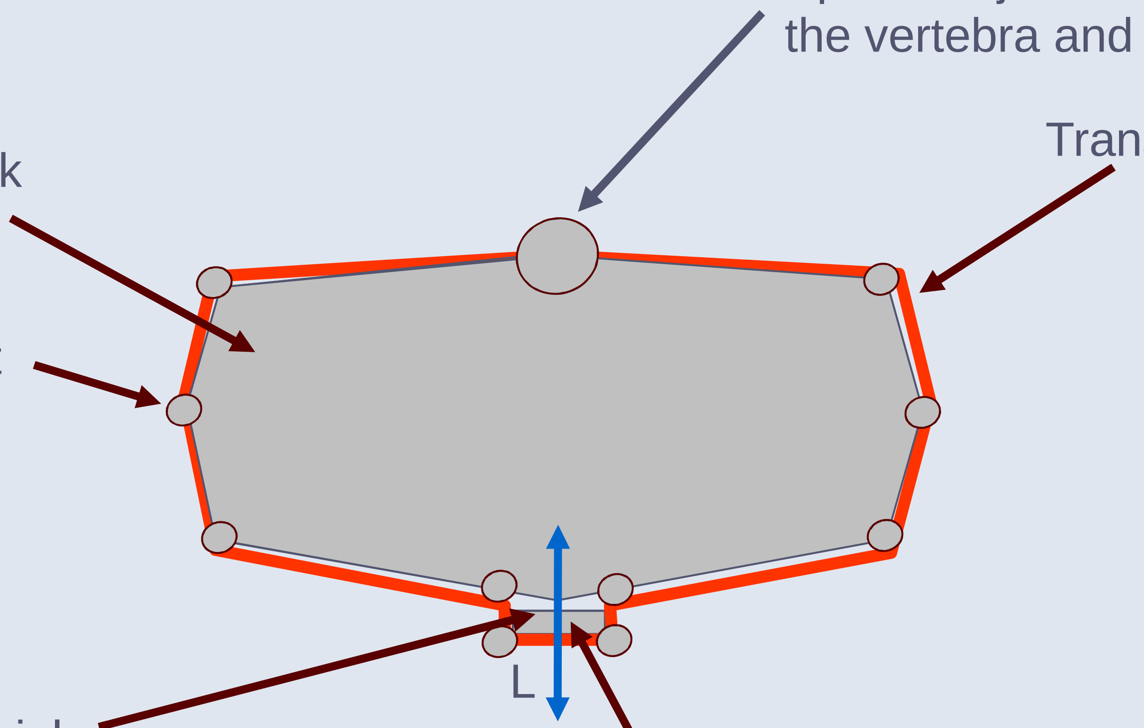
These five muscles form the only kinetic contact between the disks and the buckle. The remaining DOFs of the buckle are carried by the obliquus and rectus abdominus muscles, which are attached to the buckle

Kinetics of a disk

A reaction force acts on the spherical joint between the disc and the vertebra. This reaction force will not carry any load since all forces on the disc lie in the plane of the disc.

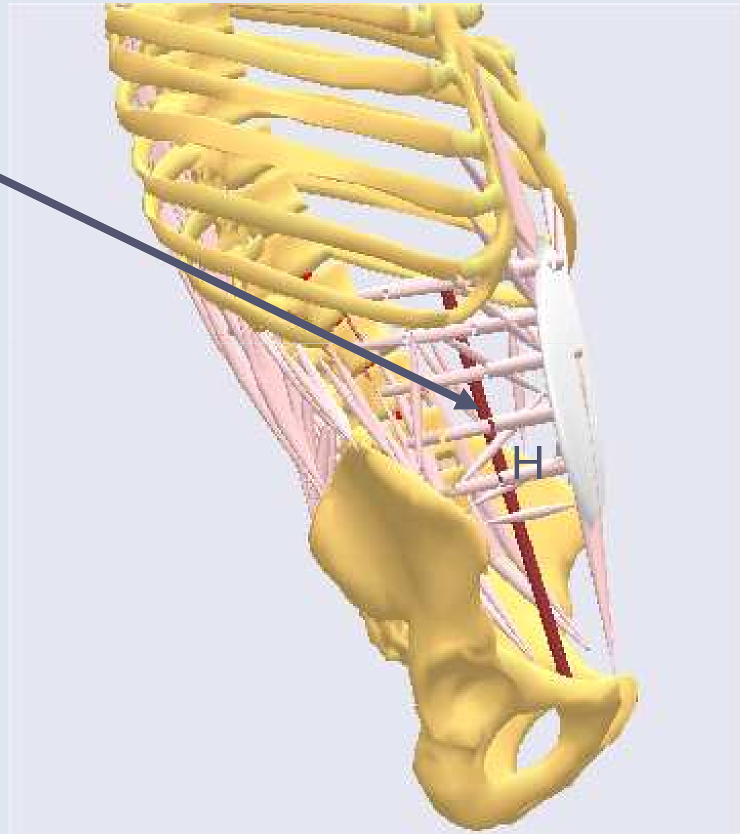


Abdominal pressure



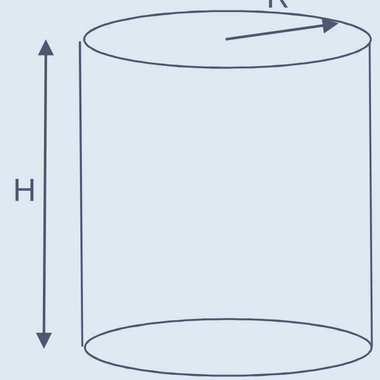
Abdominal pressure

Measure of
abdominal height H



Abdominal pressure

The volume is idealized as a cylinder, using the measures from the previous slides, the volume can be linearized in the following way



$$V = \pi R^2 H$$

$$V = V_0 + \frac{dV}{dR}\Delta R + \frac{dV}{dH}\Delta H$$

$$dV = 2\pi\, dR\ R\, H$$

$$\frac{dV}{dR} = 2\pi R H$$

$$dV = 2\pi R^2\, dH$$

$$\frac{dV}{dH} = \pi R^2$$

Abdominal pressure implementation

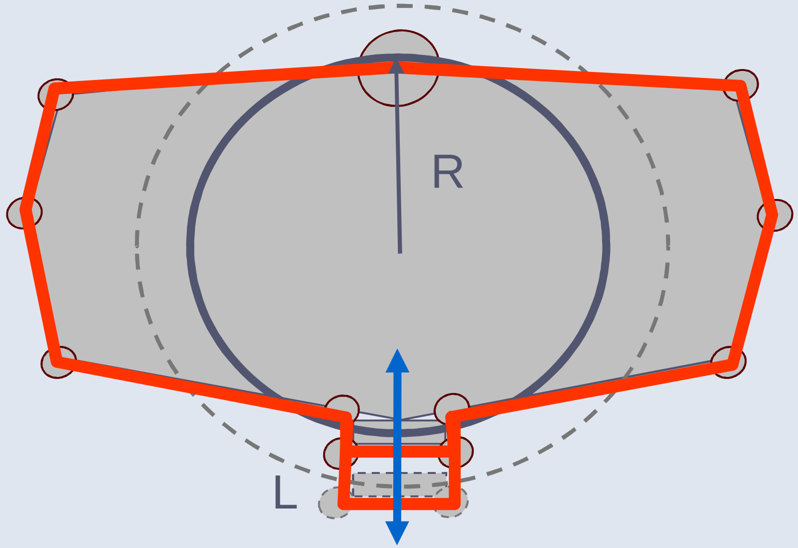
Due to idealization

$$\frac{dV}{dR} \approx \frac{dV}{dL_i} \approx 2\pi R H / 5$$

Rewriting linearized volume

$$V = V_0 + \sum_{i=1}^{5} \frac{dV}{dL_i} L_i + \frac{dV}{dH} \Delta H$$

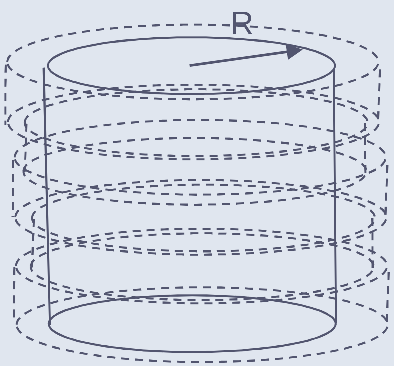
The summation is made on the five disks

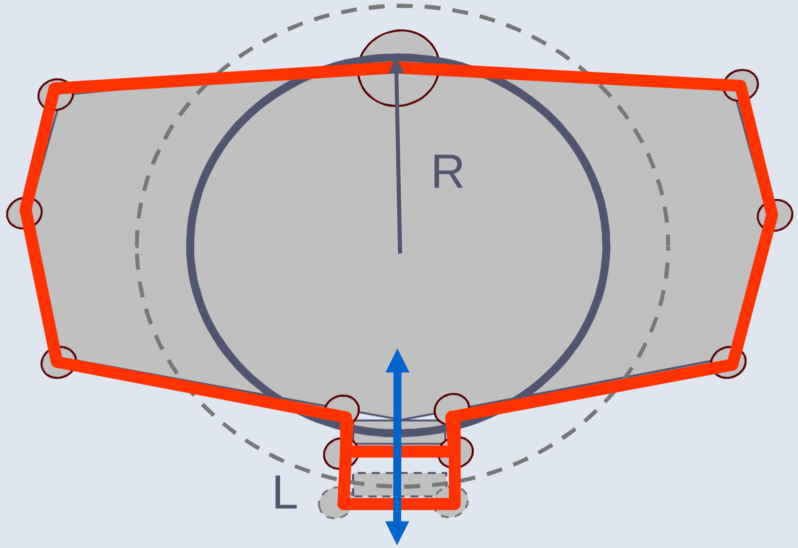


The cross sectional area of the disk is idealized as a circle with the radius R. L measures the displacement of the artificial segment. When L increases it is equivalent to an increase in R.

The artificial segment on each disk attached to the transversus muscles is balanced by the abdominal pressure and the force in the tranversus muscle

Abdominal pressure implementation





When the tranversus muscles changes length the volume measure is affected by a changed radius

Abdominal pressure implementation

The volume is made as a linear combination measure

```
AnyKinMeasureLinComb  AbdominalVol= {
   AnyKinMeasureOrg &L1=.Disc1.Disc.VirtuelSegDiscJnt;
   AnyKinMeasureOrg &L2=.Disc2.Disc.VirtuelSegDiscJnt;
   AnyKinMeasureOrg &L3=.Disc3.Disc.VirtuelSegDiscJnt;
   AnyKinMeasureOrg &L4=.Disc4.Disc.VirtuelSegDiscJnt;
   AnyKinMeasureOrg &L5=.Disc5.Disc.VirtuelSegDiscJnt;
   AnyKinPLine &ref7=.JointsAndDrivers.H;

   AnyVar Disc1Coef =  2*pi*R*H0*1/5;
   AnyVar Disc2Coef =  2*pi*R*H0*1/5;
   AnyVar Disc3Coef =  2*pi*R*H0*1/5;
   AnyVar Disc4Coef =  2*pi*R*H0*1/5;
   AnyVar Disc5Coef =  2*pi*R*H0*1/5;

   AnyVar R = 0.12; //equivalent radius
   AnyVar Area=pi*R^2;
   AnyVar H0=0.28; //initial height

   AnyVar dvdh=Area;
   AnyVar F=1;

   Coef={

{F*Disc1Coef,F*Disc2Coef,F*Disc3Coef,F*Disc4Coef,F*Disc5Coe
f,F*dvdh}
   };

   Const={F*H0*Area};

  }; // Measure
```


Example file: BRep/Aalborg/Spine/Buckle.any

Abdominal pressure implementation

An artificial muscle is working on the volume

```
 //1 mmHg = 0.133 kPa  Pa=N/m^2
  //A maximum pressure of 200mmHg was found in Morten Essendrop's Ph.D. report
  //SIGNIFICANCE OF INTRA-ABDOMINAL PRESSURE
  //IN WORK RELATED TRUNK-LOADING
  //200mmHg=26.6KPa = 26.6*10^3 N/m^2

  //In the AnyBody Modeling System, if a force is applied to this volume it becomes
an abdominal pressure!
  //A muscle with a strength equivalent to the maximal abdominal pressure is working
on the volume.

  AnyVar StrengthScaleSpine =
...HumanModel.Scaling.StrengthScaling.Spine.StrengthScale;

  AnyMuscleModel AbdominalPressureMuscleModel ={
    F0= .StrengthScaleSpine*26600/1;
  };

  AnyGeneralMuscle AbdominalPressureMuscle={
    AnyKinMeasureLinComb  &ref=.AbdominalVol;
    AnyMuscleModel &ref1=.AbdominalPressureMuscleModel;
    ForceDirection=1;
  };
```

Assumptions and facts

- Only the transversus muscle can generate abdominal pressure
- There are no out-of-plane forces on the disks
- The linearization of the volume assumes that the volume can be idealized as a cylinder.
- When the tranversus muscle changes length the volume measure is affected by a changed radius

Showcase

This video shows a standing model doing three different tasks:

1. Flexion/extension
2. Lateral bend
3. Axial twist

Please notice the motion of the five individual disks and the changes of the muscle tone.