## Anatomy and pathology

The spine is a large anatomic structure crucially important for bodily structure. Figure 1 illustrates the anatomy of two adjacent vertebrae, the bones which make up the spine. Vertebrae have a relatively complex shape which presents both challenges and opportunities in medical interventions. Figure 1 provides an unrealistically clear depiction of vertebrae; vertebrae *in vivo* are covered with sinew and many procedures are performed percutaneously, respectively impeding and precluding the possibility of direct visualization of the anatomy by the operator.

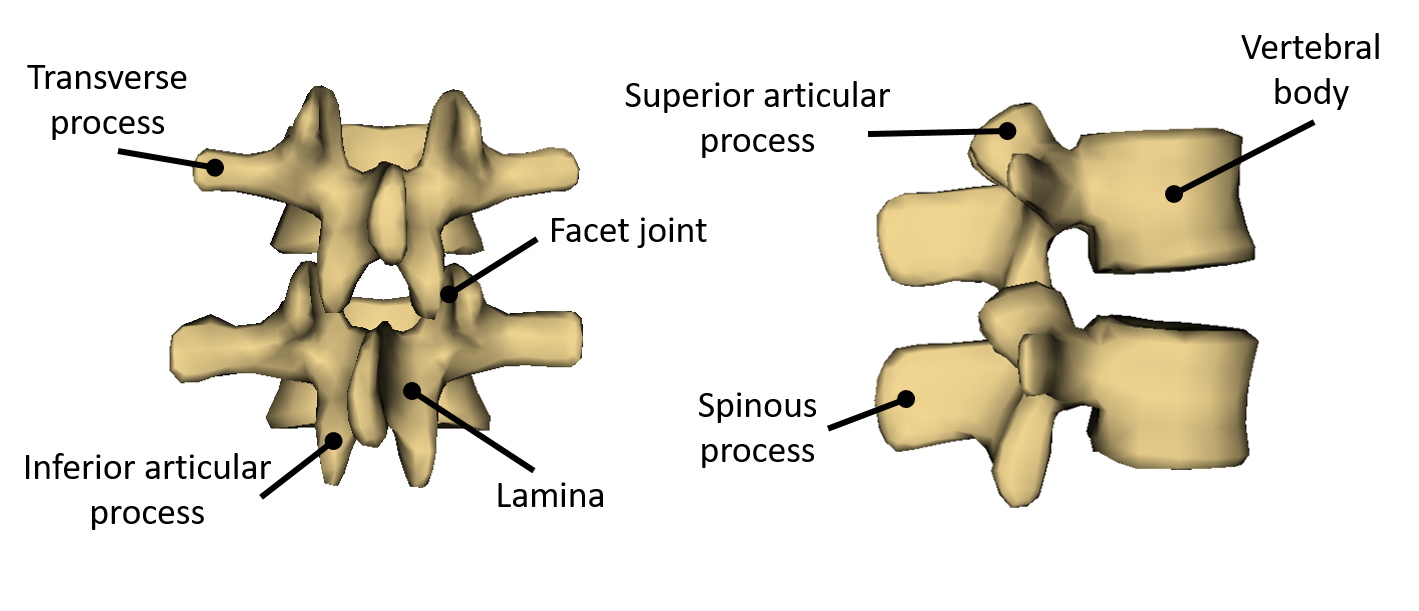


Figure : Posterior and right side views of a second and third lumbar vertebrae

The spine is susceptible to a number of diseases which can impair greater functionality through the importance of the spine.

Back pain is a prevalent health issue in the developed world, with up to 80% of adults experiencing it {sometime} [Rubin2007]. It is a leading cause for missed work and doctor visits.

## Relevant procedures

### Spinal injection

When back pain is not resolved with oral medication, the next step is often a diagnostic injection of anesthetic into the facet joint of the painful area. The small diameter of the facet joint as a target for injection, coupled with its proximity to sensitive nerves of the spine, necessitate the use of visualization of interventional navigation. Fluoroscopy or CT are currently the standards of care for facet joint injection because they provide detailed visualizations of the patient’s anatomy and needle placement. Fluoroscopy and CT require the use of ionizing radiation, and so must be performed at the specialized radiological facilities for health and safety standards. Despite these standards, fluoroscopy and CT still expose patients and practitioners to harmful ionizing radiation. The financial cost of these imaging methods and their proper operation, the radiation exposure resulting from their use, and the volume of injection procedures which they are used for, combine to impose a substantial cost of the health care system. This cost, however, may be largely unnecessary if a radiation-free imaging modality were used.

Ultrasound-based navigation for spinal interventions receives much attention in research as such a radiation-free imaging modality. Furthermore, it is gaining clinical acceptance. For example, committees commissioned by the American Society of Regional Anesthesia and Pain Medicine (ASRA) and jointly by the ASRA and the European Society of Regional Anesthesia and Pain Therapy both report positive recommendations for training and practice with ultrasound guided regional anesthesia (UGRA) [Sites2009, Neal2016].

The simplest method for ultrasound injection guidance involves holding the probe so that the image plane contains the path of the needle [Hurdle2016]. More sophisticated methods involve the registration of prior CT or MRI scans to intraoperative, spatially tracked ultrasound. Inter-modality image registration-based visualization produces models suitable for assessment and injection guidance, however many patients will not have had prior CTs and performing CTs for this purpose reintroduces the problem of harmful radiation. MRI is not an ideal solution either due to its limited availability and high cost. Methods have also been proposed which require only ultrasound as an imaging modality, wherein a statistical atlas models of vertebrae are registered to patient ultrasound. Atlas registration methods have shown some promise both *in vitro* and *in vivo*, but to our knowledge, have not been validated against abnormal anatomy. Abnormal spinal anatomy, such as scoliosis, may prove challenging for statistical atlas generation. [Shape + pose both affected]

## Ongoing US research

### Inter-modality registration

### Atlas registration

## Proposed contribution