Introduction: Each year, over 100,000 Canadians undergo joint replacement surgery to restore mobility and alleviate pain. Implant longevity can be maximized through optimizing implant fixation, reducing cartilage wear and preventing infection. These are active areas of research as revision surgeries to replace failed components have numerous negative implications, including poorer outcomes, greater risk of infection, and additional cost to the health care system. We have previously described the creation of a custom rat hip component through micro-CT image-based design and 3D metal printing for more rapid preclinical testing of novel implant features aimed at improving implant longevity. However optimization of our prototype implants and their associated surgical toolkit is critical to ensure repeatable installation of components in future studies using this model. Moreover, a system to monitor implant position in situ during locomotion would further enhance assessment of treatment efficacies using the rat partial hip replacement model. Thus, we describe two pilot studies: (1) the installation of our custom 3D metal printed implants into live rats, and; (2) the creation of a radiolucent treadmill for fluoroscopic imaging of rodent skeletal anatomy during locomotion.

Materials and Methods: (1) Partial hip replacement to install components into live rats (n=2; 900g and 500g) was performed. The femoral head was resected using a dental drill. A combination of dental reamers and files was used to prepare the inner femoral canal prior to implant insertion. Micro-CT and X-ray fluoroscopy were performed post-operatively at 1 day, 3 weeks and 12 weeks to evaluate the position of each component within the femur of each animal. (2) Carbon fibre tubing was used to support a ventilated acrylic enclosure, which houses the treadmill. A commercially available rat treadmill belt (90 x 10 cm, Harvard Apparatus) was mounted between two plastic rollers (3.8 cm diameter) attached to low-friction plastic bearings. Deterrent rails were placed in close proximity to the rear roller to prevent the animal from falling below the treadmill. A laptop controlled stepper motor was rigged to a rubber drive belt to power the unit. The completed unit (51.0 x 15.8 x 13.3 cm) was then integrated with a commercially available micro-CT scanner (eXplore Ultra, GE Medical), modified for high-resolution fluoroscopy at 60 Hz and tested using live rats.

Results: (1) The 900g rat showed no evidence of implant migration or dislocation at any time point, and survived on its component for 11 months. The 500g rat however showed evidence of implant migration at 3 weeks and full dislocation at 12 weeks. (2) Fluoroscopic videos of the rat running at speeds of 12 cm/s and 25 cm/s were acquired. Hind-limb anatomy was visualized over multiple consecutive gait cycles. Clear visualization of the bone boundaries was achieved, although some blurring was observed during peak limb swing velocities. No confounding artifacts from the treadmill were observed overlaying the skeletal anatomy.

Discussion: We have shown that long-term fixation of 3D printed components in rat model is feasible, but improvements can be made to the implant and surgical toolkit to ensure repeatable installation, fixation and stability. The addition of features such as collar and surgical tools such as a custom broaching system are aimed at helping to ensure both initial and long-term fixation of implants. Further pilot studies in cadaver and live animals will be necessary to validate our new features and tools, as well as yield improved iterations of our prototypes. We have also demonstrated that x-ray fluoroscopy in the bore of a commercially available small-animal scanner is possible for visualizing locomotion in rats. Subsequent iterations of our device will include a self-pacing mechanism to increase the efficacy of hind-limb visualization during the entire scan duration. Future studies will include larger sample sizes longitudinal analysis of rats before and after installation of our novel 3D metal-printed implants. Both the implants and treadmill are the first of their kind. Together they will allow us to, for the first time, utilize a readily available small animal model to test functional implant features aimed improving implant longevity after joint replacement surgery.