Objective:
Prevention of pulmonary embolism is the major indication for placement of filter systems in the inferior caval vein (ICV). Consisting of stainless steel or Nitinol, susceptibility artifacts preclude a precise evaluation of intra filter thrombi with the aid of magnetic resonance imaging (MRI). RF artifacts and shielding effects considerably reduce a precise intra-filter MRI. To overcome this disadvantage, a resonant circuit consisting of a parallel inductivity and a capacitor tuned at the RF-frequency of the MRI (42 MHz per Tesla), were integrated in a Nitinol based detachable caval filter system. This technique focuses the RF energy inside, resulting in an augmented flip angle and improved imaging. This study describes the effect of such an active venous caval filter (VCF). Signal increase by this aVCF, the feasibility of deploying the filter solely using MRI guidance and its efficiency in filtering thrombi were examined.

Methods:
The active venous caval filter (aVCF, 70 mm length, 20 mm diameter) consists of eight Nitinol loops, forming the coils with the capacity build-in. This orientation creates a resonant circuit tuned at 63 Ms⁻¹, the Lamor frequency at 1.5 Tesla. The folded self-expanding aVCF is attached at the tip of a 9 F catheter and can be developed and cloaked as well as deployed by the interventionalists from the distal part of the catheter.

The interventions were accomplished in six pigs in general anesthesia. Venous approach was established via a 16 French venous sheath (Avanti, Cordis Corp., USA) placed in the right femoral vein. MRI was performed in a 1.5 Tesla whole body scanner (Achieva, Philips Medical Systems, The Netherlands) using a 5 element surface coil. To evaluate the MR imaging properties of the aVCF four balanced SSFP sequences were performed, before and after filter deployment. Except of a different flip angle (FA = 90°, 40°, 25°, 15°), the five SSFP sequences were identical: TR 3.06 msec, TE 2.53 msec, NSA 1, field of view (FoV) / matrix 530 / 512 mm, slice thickness 6 mm, slice gap 0.6 mm, 32 slices in transverse and 9 in coronal orientation. Using a real-time balanced-SSFP sequence (TRs 3,4 msec, TE= 1.72 msec, FA 40°, FoV / matrix 320/224 mm, sliding window-technique, approximately 3 images per second), the aVCF was placed and deployed in the center of the receiver coil and the center of the field of view.

After deploying the aVCF and controlling the correct filter using X-ray fluoroscopy, an extra-corpal produced thrombus was washed into ICV via the venous sheath. To assess intra-filter thrombi, additionally to SSFP a proton density weighted (PDW) TSE sequences and a time-resolved 3D-MR-Angiography were measured. At the end of the experiments, the filters were recovered by autopsy to proof the intra-filter thrombi and to visually verify the MRI and the filtering function.

To evaluate the signal enhancing of the aVCF, signal intensities were determined on five centre slices of the axial SSFP images before and after filter placement in the ICV (without the aVCF and inside the aVCF), in the aorta, the left psoas muscle and in the air ventral of the abdomen (Fig. 1). On five more distal slices without any aVCF, the signal intensities were measured in the aorta and in the psoas muscle on the same sequences. Averages of the five corresponding values were calculated. Thereof, signal-to-noise ratios (SNR) were determined for the ICV, the aorta, the muscle and the distal aorta and muscle, respectively. Contrast-to-noise ratios (CNR) against the muscle signal were assessed for the ICV, the aorta and the distal aorta. For statistical comparison between the pre- and post-filter values and to evaluate differences between sequences with different FA’s, Student’s t tests and signed ranked tests were performed and probability values (p-values) were calculated.

Results:
In all six animals, filter placement was successfully performed explicitly using real-time MRI guidance (Fig. 2), with an obvious enhancing effect. Fluoroscopy (Fig. 3) proved the correct position. In all cases, intravenous thrombi were successfully filtered by the aVCF and visualized by SSFP, PDW and MRA sequences (Fig. 4). Autopsy confirmed these results (Fig. 5).

Statistical analysis revealed highly significant differences (p<0.01) in SNR and CNR of the ICV with and without aVCF and no significant differences in the other regions of interest. This indicates that the aVCF leads to an increase of SNR and of contrasts but does not influence its direct surroundings. The effect of the filter was significantly (p<0.05) pronounced in low FA’s (Fig. 6), however the increase of noise reduces the image quality additionally.

Conclusion:
This study shows the feasibility of a fully MRI guided deployment of an effective ICV filter system. Moreover, installing a resonator in such a device the signal intensity inside the aVCF is significantly augmented. This enhancement is also depending on the FA with small FA leading to a higher relative signal increase. However, as noise becomes more pronounced in low FA’s, intermediate FA result in better image quality with still very high aVCF-induced contrasts. Consequently, this aVCF facilitates a detailed imaging and assessment of thrombi within the filter, which was also visually validated post-mortem. Moreover, this aVCF can be applied and monitored during therapy solely using MRI.