A Guide to Clinical Use of FIDEX

V 1.0, September 07, 2013

Foreword

This Teaching File was put together by two active users of Fidex with some editorial help from Animage. Motivation for this work was twofold:

1. CBCT is still a new technology lacking textbook support. The new user should not have to go through a long learning process with trial and error. In that sense, this Teaching File is like a collection of recipes.
2. As common to all advanced imaging modalities, Fidex CBCT is not a simple push-button instrument giving automatically optimal image results. It requires
   - good preparation of every scan
   - correct choice of techniques
   - knowledge of what to expect from a CT scan in order to understand the scan results.

This File is complementary to the User Manual, and is focused on real world application of the scanner. Working through it and keeping it as a resource for reference during scan set-up should help the new Fidex user to obtain good results from the get-go.

The file is organized as follows:
Section 1 is a short introduction to technical features of the scanner. This is a repetition of information contained in the User Manual.

Section 2 talks about indications for CT in general. While CT is called the workhorse of radiology, it may not be the optimal modality for all suspected maladies of the patient. A CT scan should only be ordered if medically indicated.

This section covers the bulk of this file: discussion of CBCT application to various body parts of common companion animals (dogs, cats). This is where one can find the recipes for daily use of the scanner. Many images are found here to train the new user and shape his/her expectations.

Section 3 is about patient positioning.

Section 4 talks about contrast application. In many cases, CT scans with and without contrast are necessary for diagnosis. Practical advice is given about contrast media, amount, timing etc.

Section 5 explains how to control breathing of the animal during the scan which would otherwise create motion artifacts in the image.

Section 6 contains clinical examples, altogether 27 case studies. This is the main part of the File, and it can be consulted after the decision to scan has been reached and preparations have to be made. The cases are presented in a short-form report with image examples. The electronic form of this File allows magnification of the images.

The appendix finally talks about limitations of the technology and Fidex in particular: e.g. patient size, scan speed etc. Practical advice on parameter choice is included A list of typical artifacts is presented here with some advice how to mitigate them, or how to recognize them as such.

We wish all users of Fidex good success in the application of this versatile instrument, and hope that this Teaching File will help to shorten the learning phase for the benefit of both the patients and the clinic. Please keep in mind that this is not a textbook. It is based on the rather short experience of two users. We plan to make updates to this, so please submit your comments to hbruning@animage.com .

Pleasanton, CA in September, 2013

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CBCT

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Section 1: How Cone Beam CT works

History: what CT does; single slice, helical, multi-slice, cone beam

CT has developed into one of the most important radiological tools. Even as MRI has become popular due to its superb soft tissue contrast and absence of radiation, CT has remained the work horse of diagnostic imaging for humans due to the clarity of its images and the intuitive interpretation of them. The following is a very short overview of how CT works:

Classical CT received its first practical implementation in 1969 by Geoffrey Hounsfield (although the mathematics was developed earlier). This developed into a system employing a single arc of about 1000 detector elements opposite powerful x-ray tube. Both are mounted on a gantry with a central opening for the patient. While the gantry rotates around the patient, a large number (about 1000) of 1-D projection images are acquired.

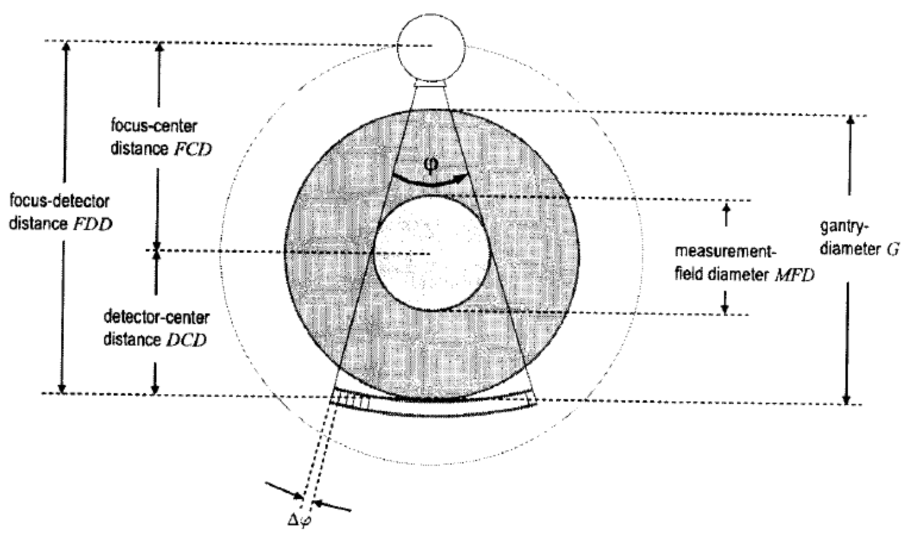


Figure 1 Fan-beam CT scanner

All commercially available human CT scanners employ this basic 3rd generation geometry.

The process that leads from the set of 1-D projections to a cross-sectional, 2-dimensional image is called image reconstruction. This image is also called slice, hence the name tomography from tomos = slice. The most popular reconstruction method is filtered back-projection but other methods (e.g. Fourier-based methods or algebraic methods) are also available. The basic steps are:

(1) Projection preprocessing including weighting to handle geometry and detector non-idealities.

(2) Filtration along the detector arc for de-blurring. This can be done in the spatial domain through a process called convolution, or, more efficiently, in the Fourier domain. In this process step, the trade-off

between spatial resolution (sharpness) and image noise is accomplished. The convolution kernels are the so-called algorithms, and they are being treated as trade secrets by the manufacturers.

(3) The next step is back-projection, where the values of the filtered projections are distributed along straight lines from the detector to the focus. All image pixels receive a contribution from each projection.

(4) The final step is called accumulation and normalization: all contributions per pixel are summed and then normalized and shifted to obtain so-called Hounsfield Units for the density they represent. Water has 0 HU, air has -1000 HU, and bone has 500 to 2000 HU.

(5) In order to present the image, one then has to map the density values of the pixels to a grey scale. Conventionally, low HU are displayed dark, and high HU are displayed as light. The image can be manipulated by changing window and level (W/L), or contrast and brightness.

Single-slice CT machines evolved over the years into multi-slice scanners which employ 2, 4, 8, 16 or even more parallel arcs of detector elements allowing obtaining several slices per rotation. In addition, the advance of helical scans (rotating continuously while the patient table moves the patient through the x-ray field) helps in many cases to reduce the overall scan time. Note that the resulting stack of slices can be viewed as a 3-dimensional image using a secondary image reconstruction. This is called MPR (multi-planar reconstruction) or volume rendering.

A straight-forward extension of these multi-detector row scanners has led to the development of cone beam scanners, which employ 2-dimensional detector panels (as opposed to rows of 1-dimensional arcs). In a CBCT scanner, a set of 2-D projections are transformed into a 3-D voxel image of densities. The most popular image reconstruction method is again filtered back-projection, and the practical implementation was introduced by Feldkamp, Kress and Davis in 1984. The first commercial CBCT scanners came out in the 1990’s, and they are the method of choice for 3-D Angiography, non-destructive testing, and dental 3-D imaging.

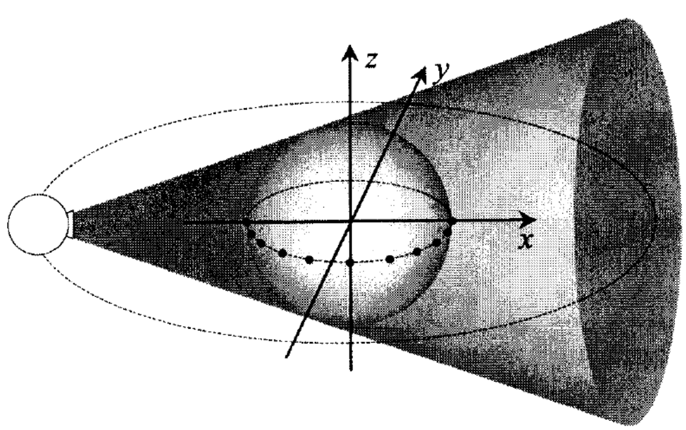


Figure 2 Principle Cone Beam CT scanner

The beauty of CBCT is both that it collects enough data in a single gantry turn to reconstruct a sizeable volume and the fact that it has the potential to reach much higher spatial resolution due to the small pixel size of 2-D detector panels. Also, the tube output is used more efficiently because many more x-rays are obtained in the cone compared to a thin fan.

The mathematics is a bit more complex than for conventional FBP, and the sizes of the data sets are orders of magnitude larger and require more computing power, but the steps are essentially the same:

(1) 2-D projection preprocessing and weighting.

(2) Filtration (or convolution) is conveniently realized as many 1-D filtration steps along the detector rows. This is actually the main invention of FDK, and it involves an approximation (with some artifacts), but it also led the way to practical solutions.

(3) Back-projection: this is now done in 3 dimensions, and the accumulation is done in voxels (as opposed to pixels which all lie in the plane of a single slice). Mathematically, the back-projector uses so-called projective matrices which incorporate the complete geometry information of the scan. Back-projection takes a large percentage of the total reconstruction time.

(4) Accumulation and normalization complete the FDK algorithm.

(5) Images are now presented as stacks of slices. Typically, the 3-D images are isotropic with the same resolution along any of the 3 axes. So for the first time, we get high quality images in the sagittal or coronal direction when using a secondary image reconstruction. So here we have the first real 3-dimensional imaging device.

Major steps in image generation

Let us quickly review the inner workings of a CBCT machine designed for veterinary imaging: Fidex made by Animage, LLC in California. As opposed to CT scanners for humans, this product is designed for smaller patients (but it is larger than dental CBCT scanners in order to allow abdominal scans of companion animals).

i. Data acquisition: geometry, projections, preprocessing.

Data acquisition uses a (dynamic) flat panel detector as also used for digital fluoroscopy. The panel has 1024 x 1024 pixels of 0.127mm size. The spatial resolution in this product is actually determined by the size of the x-ray focal spot of 0.6mm or about 0.2mm at isocenter. The detector is read-out in a 2x2 binned mode in order to increase acquisition speed. Fidex collects 512 or 745 projections per gantry turn, and allows image reconstruction with various spatial resolution from 0.16mm to 0.45mm. Note that this is also the slice width (isotropic voxels).

ii. Data acquisition: PreView, scan modes, projection

Before a CT scan is started, it is good practice to run a PreView (also called Topogram or Scoutview): the collimator narrows the x-ray field to a slot, and the patient is moved through the scan range to obtain a 2-D projection image with up to about 50cm of length along the z-axis. This Preview is then used to determine the scan range making sure the region of interest will be covered. From the same images, the user sets the scan diameter of the measurement field. The machine will then position the table and the x-ray camera accordingly, and collect the necessary data.

iii. Tomographic image reconstruction: FDK, algorithms, computer implementation.

The image reconstruction (sketched above) is implemented using high-end gaming graphics cards from nVidia. The set of about 500 slices obtained in a single gantry turn takes about 20 seconds to reconstruct, roughly the same as data acquisition. The amount of data handled is impressive: e.g., 512 projections of 0.5 MB each need to be filtered involving 262,144 x 2 Fourier transformations and 512 x 134 million voxel back-projections/accumulations. We are deeply grateful to the gaming industry that pushed the limits of image processing.

A portion of the reconstruction time is spent on corrections of physical effects which would otherwise lead to artifacts in the image. Corrections are done for inhomogeneous x-ray field, detector response, beam hardening, scatter, cone-beam artifacts (FDK is an approximation). Details are discussed in section 2.b.

A very important feature of image reconstruction is the ability to stitch together adjacent volumes to generate one large volume along the z-axis. This way, stop-and-shoot CBCT machines like Fidex can produce CT scans that are almost 60cm long, suitable for a full thorax.

Note that the gantry turns rather slowly at 10 – 20 sec per turn. This is caused by the finite read-out speed of the detector panel, but it also allows leaving the gantry open and accessible instead of having to confine it in a closed space as in fast-turning CT scanners. Cone Beam data acquisition and image reconstruction are therefore well matched. If future computer hardware allows faster reconstruction, we can hope that progress with dynamic flat panels will match this by allowing faster read-out.

Section 2: Indications for a CT exam

External, medial and inner ear examination.

In the presence of recurrent otitis, vestibular syndrome , and facial hemiparesis a CT exam is indicated. There can be evidence of middle and inner ear infections (osteomyelitis of the bulla), masses (e.g. benign nasopharyngeal polyps or tumors), trauma, foreign bodies of the external and middle ear.

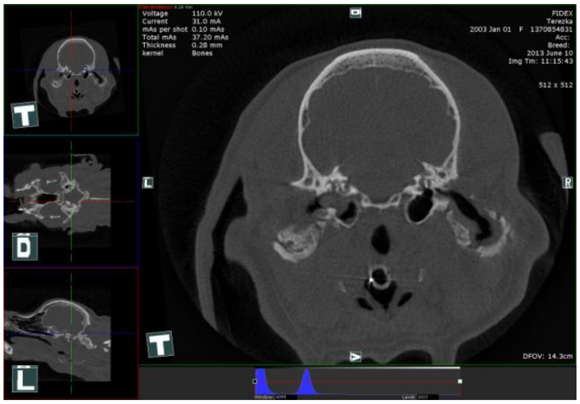


Figure 3 Chronic otitis externa with mineralisation

Figure 4 otolithiasis left bulla

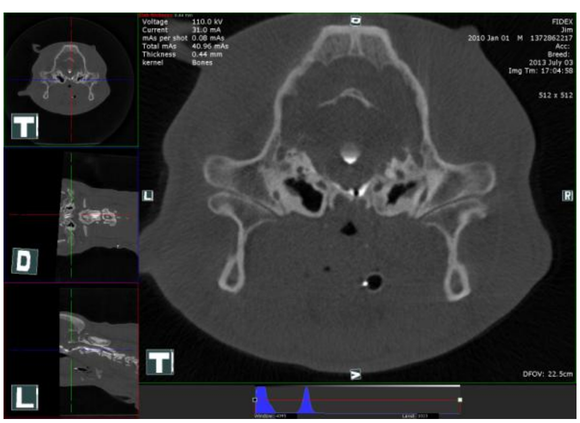


Figure 5 craniomandibular osteopathy both bullae

Exploration of the orbital region

We indicate CT scans in the presence of proptosis, a facial asymmetry , an ocular neurologic deficit, epiphora , suborbital fistula , pain when opening the mouth , trauma . A CT scan may be needed to highlight abscess, foreign bodies, or retro-orbital tumors.

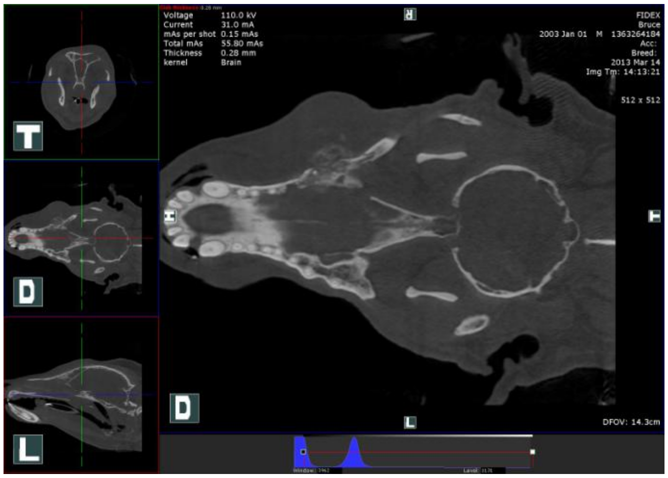


Figure 6 fibrosarcoma upper jaw

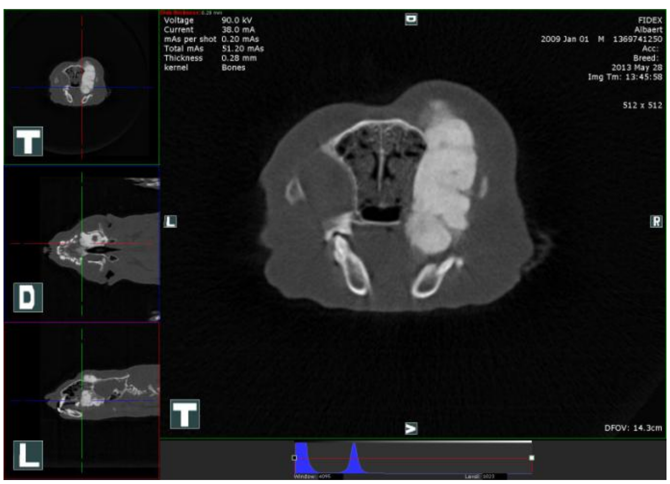


Figure 7 osteo-chondrosarcoma skull ferret

Exploration of the nasal cavities

In the presence of sneezing, of unilateral or bilateral discharge, deformation of the nose, CT is used. It can highlight. foreign bodies, bacterial and fungal infections with lesions destructing the nasal turbinates, neoplasia of nasal cavities as well as invasive tumors of the hard palateand sinus formation from dental disease.

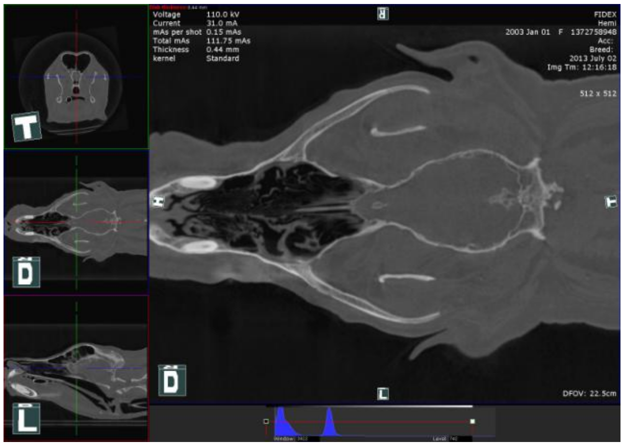


Figure 8 nasal aspergillosis right nasal cavity

Figure 9 physiologic nasal cavities, dog

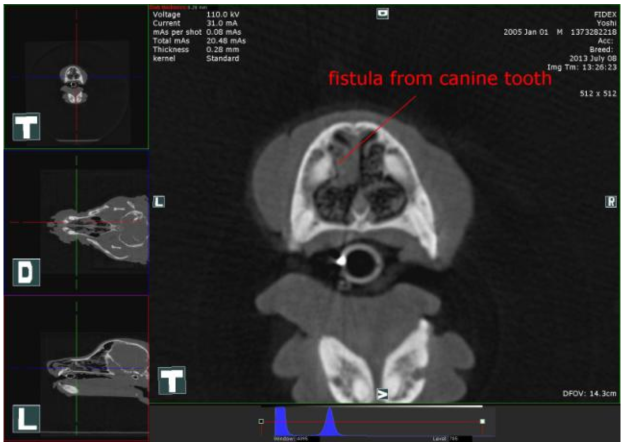


Figure 10 fistula from canine tooth to the nasal cavity

Exploration of Oral Cavities

An other important indication is dental disease (perapical infections, abscess formation, tooth fracture, mandibular fractures), temporo-mandibular joint disorders (luxation, ankylosis, fractures) , neoplasia of mandibule and surrounding soft tissues (surgical planning). Foreign bodies and salivary glands can be imagined by the CT.

Figure 11 osteosarcoma of the mandibula

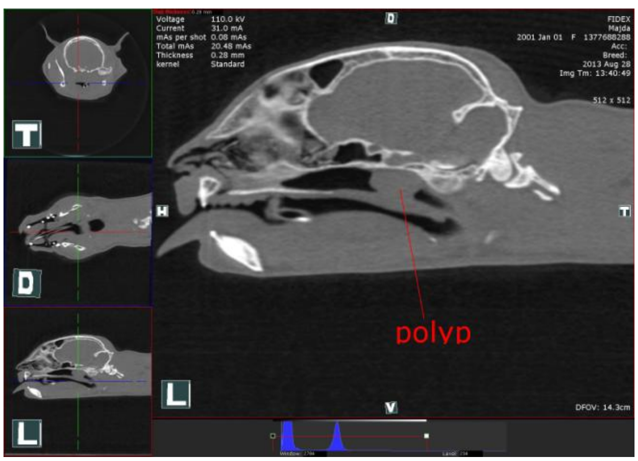


Figure 12 nasopharyngeal polyp, cat

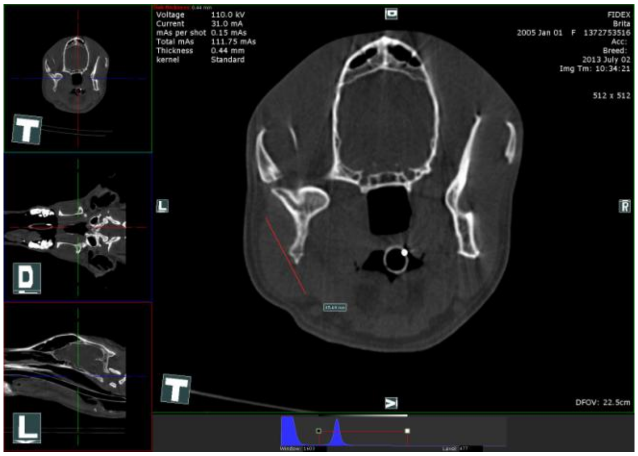


Figure 13 salivary gland infection

Exploration of the central nervous system

In the presence of a central vestibular syndrome, cranial nerve disorders, ataxia, amaurosis , epileptiform seizures , atypical behavior disorder, trauma. CT can demonstrate congenital or acquired disorders, occipital malformations, stroke, post -traumatic edema, skull fracture, neoplasia

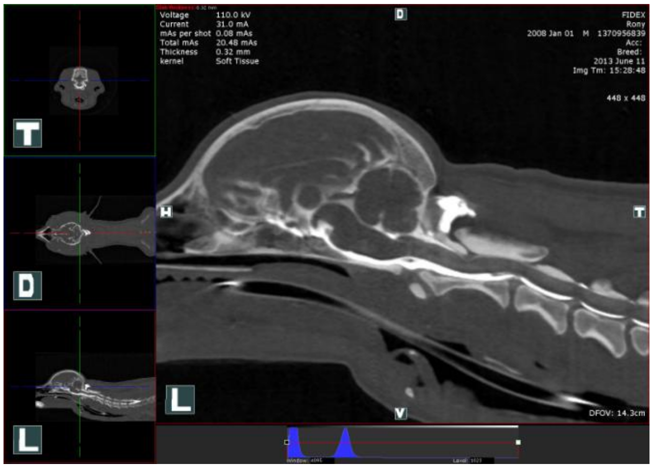


Figure 14 artificial enhancement of the brain after myelography

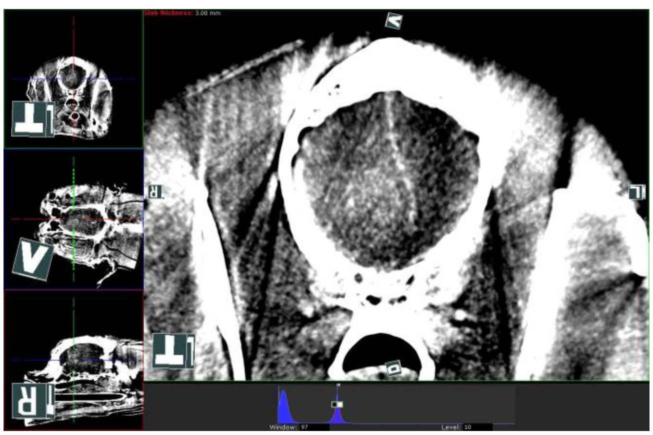


Figure 15 contast enhanced brain tumor causing midline –shift

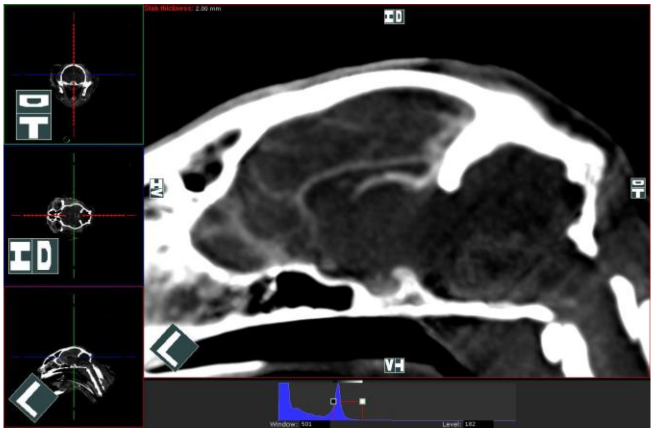


Figure 16 physiological brain and pituitary gland, cat

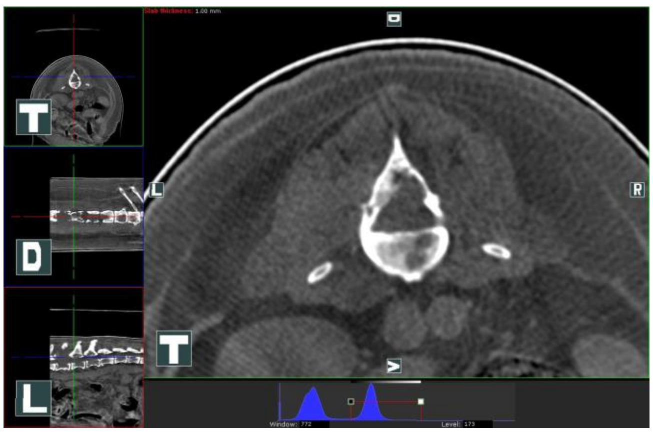


Figure 17 multiple myeloma – lytic lesions in the vertebrae

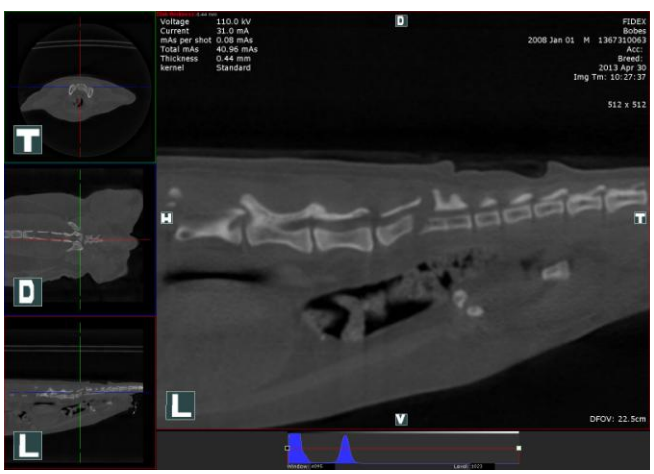


Figure 18 dislocated sacral fracture in a cat

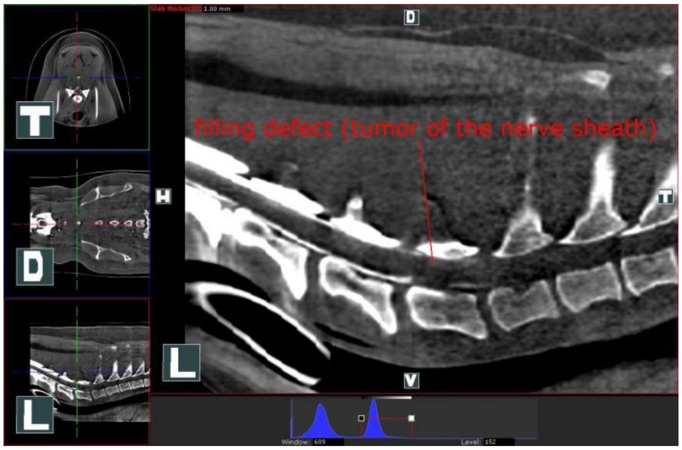


Figure 19 golf-tee sign caused by a spinal tumor

Exploration of the spine

CT is used for demonstration of disc pathology as herniations or infection, fractures and luxations of vertebrae, spinal cord lesions (subarachnoidal cysts, dural and intradural masses), vertebral deformity , spinal joint instability (caudal cervical instability, lumbosacral instability), extradural neoplastic lesions and metastasis of the bony structures.

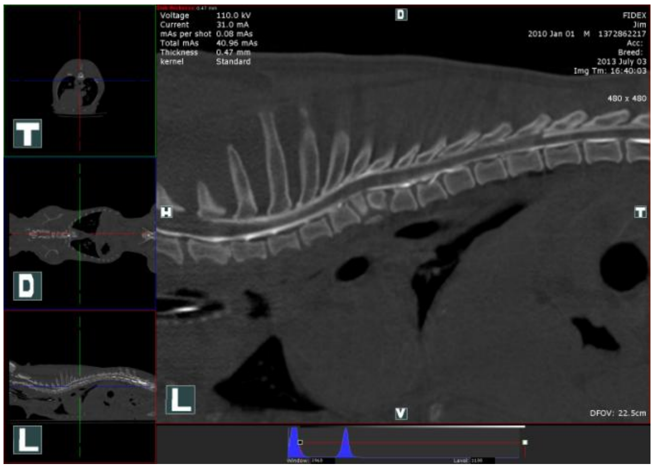


Figure 20 congenital anomaly in a French Buldog

Figure 21 Disk extrusion

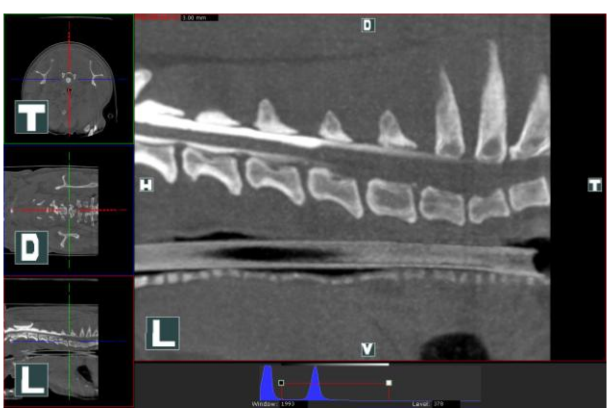


Figure 22 subarachnoidal cyst

Orthopedic disorders

A CT exam is extremely useful in many cases of lameness and trauma. Major indications for joint disease are evaluation of elbow dysplasia (medial coronoid disease, incongruency), osteochondrosis, stifle disorders (miniscus lesion, cruciate ligament disease), hip dysplasia, joint luxations and complex intraarticular fractures, infections and joint neoplasia. In high grade patella luxations with angular deformities CT is also useful. In long bones the indications are fractures, osteomyelitis, bone healing disorders and neoplasia. Growth deformities for preoperative planning. Other indications are pelvic fractures and luxations especially complex acetabular fractures for preoperative planning.

Figure 23 fragmented medial coronoid process

Figure 24 ununited ancoaeal process

Figure 25 OCD, stifle joint

Exploration of the chest

Presence of chronic cough, chest trauma, swelling of chest wall etc. CT can demonstrate the presence of pulmonary or mediastinal masses, lymphadenopathy , effusion, pneumothorax or atypical lung disease (e.g fibrosis, bullae) . CT is especially usefull for surgical planning (lung lobe torsion or lung tumors) and to determine the location, size and origin of the lesion with staging (metastasis from 1 mm). Esophageal disease (foreign bodies, tumors, hernia) is an other indication.

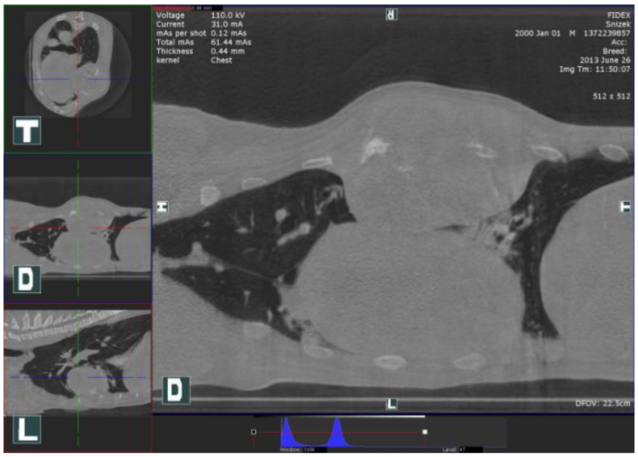


Figure 26 hemangiosarcoma, chest wall

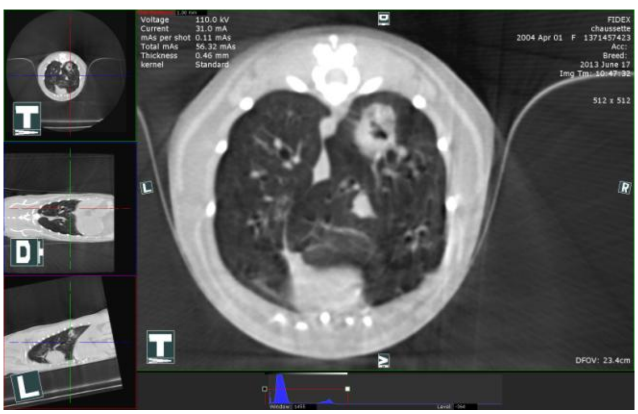


Figure 27 bronchial carcinoma

Exploration of abdomen

In general we can highlight adenopathy of intraabdominal lymph nodes, morphology of kidneys and ureters (incl. diagnostic of ectopic ureters and concrements of kidneys and ureters) tumors of urinary tract. We can also image liver size, masses, cholecystic concrements, porto - systemic shunting as well as adrenal gland size or splenic pathologies.

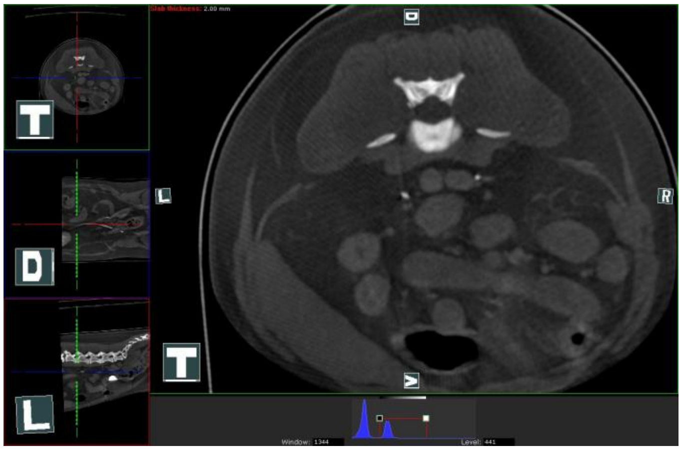


Figure 28 abdomen physiologic

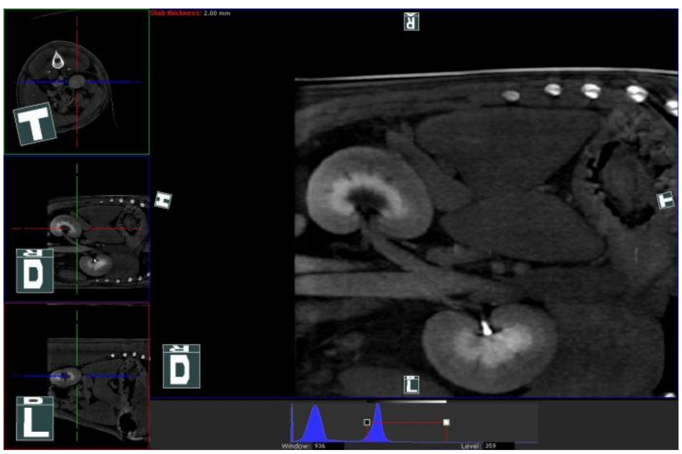


Figure 29 filling defect right kidney after contrast administration

Cutaneous and subcutaneous tissues

CT can be important for accurate topographic evaluation for oncologic resection margins of soft tissue tumors (fibrosarcoma, mastocytoma), fistulography and detection of foreign bodies. Postoperative control of complete excision can be performed with CT.

Figure 30 recidive of a cutaneous grade III mastocytoma

Special indications

Surgical planning for brachycephalic breeds. CT allows as single diagnostic modality to diagnose nearly all pathologic changes in brachycephalic breeds. This includes long or hypertrophic soft palate, abnormal turbinate, stenotic nostrils, laryngeal or tracheal collapse, hypoplastic trachea and so on. It is especially useful for preoperative planning (shortening of the soft palate vs. palatoplasty etc).

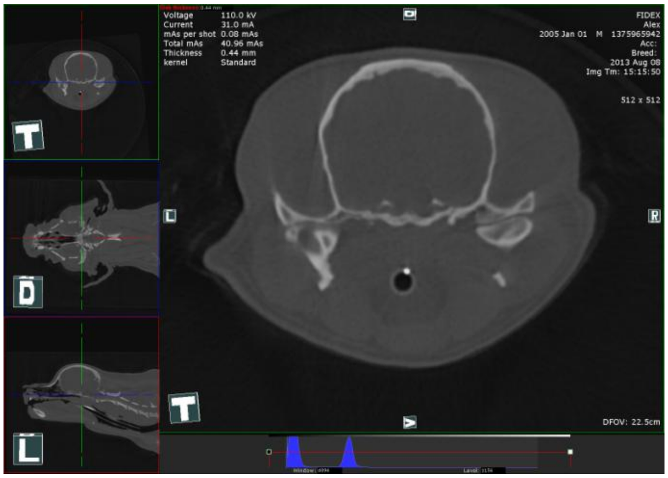


Figure 31 total pharyngeal obstruction due to hypertrophic soft palate

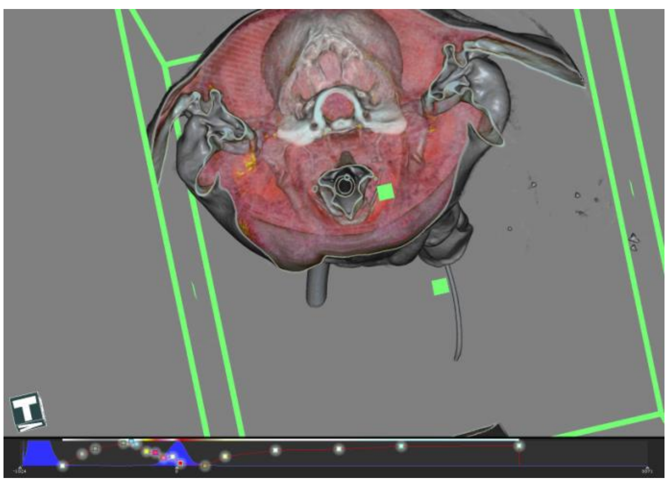


Figure 32 same patient as 31 volume rendering

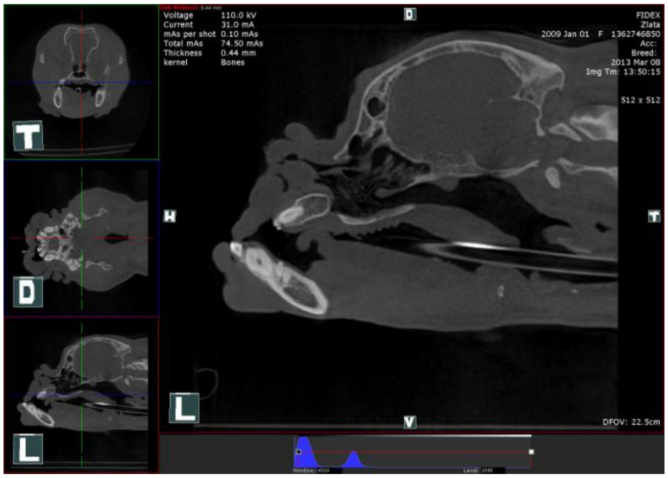


Figure 33 brachycephalic syndrome, elongated soft palate

Follow up CT exams are very useful as therapy control and postoperative scans for surgical outcome. In many instances CT is the only non-invasive technique for objective follow ups.

Exotic animal practice

CT is the method of choice in herpetologic medicine for diagnosing lung disease, esp. in snakes and chelonians. In turtles and tortoises, CT is also often indicated for other diagnostics (soft tissue, obstetrics, bony changes) due to their shells.

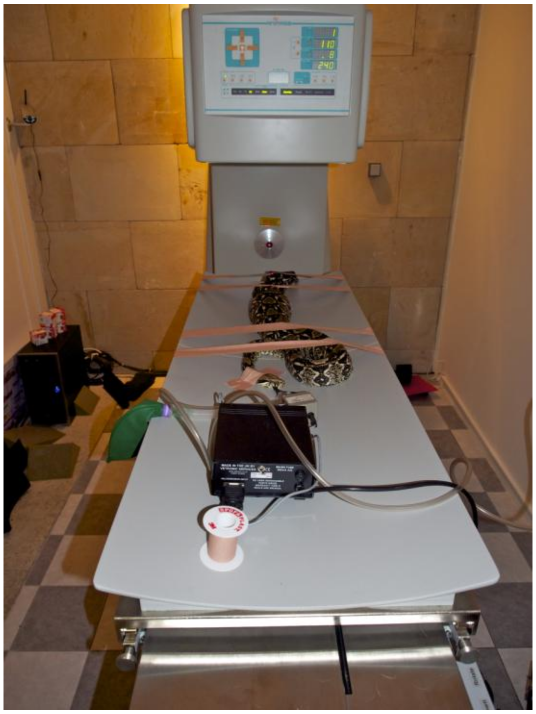


Figure 34 CT exam of Boa constictor

Figure 35 lungstudy tortoise

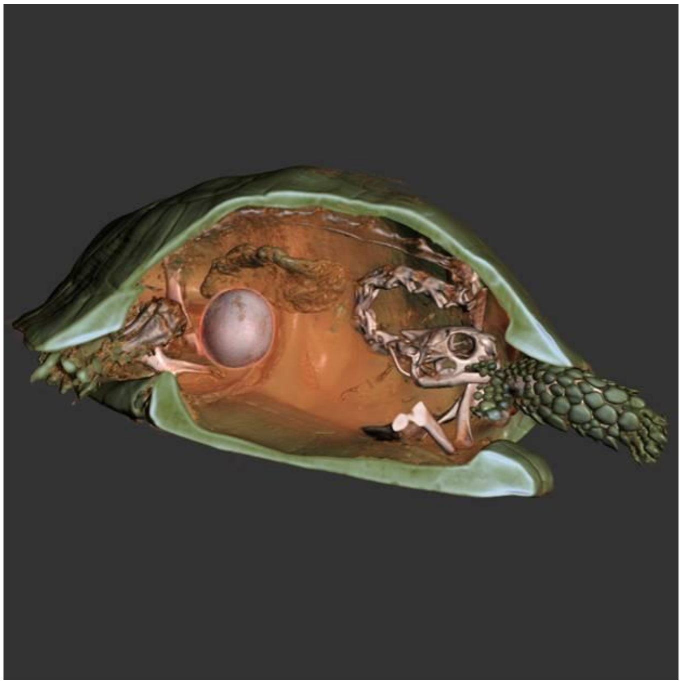


Figure 36 egg binding tortoise

The same may be true for aviary medicine.

In small mammals (rabbits, guinea pigs etc) CT can be superior diagnostic technique for dental problems (abnormal growth of teeth, malocclusions, abscesses).

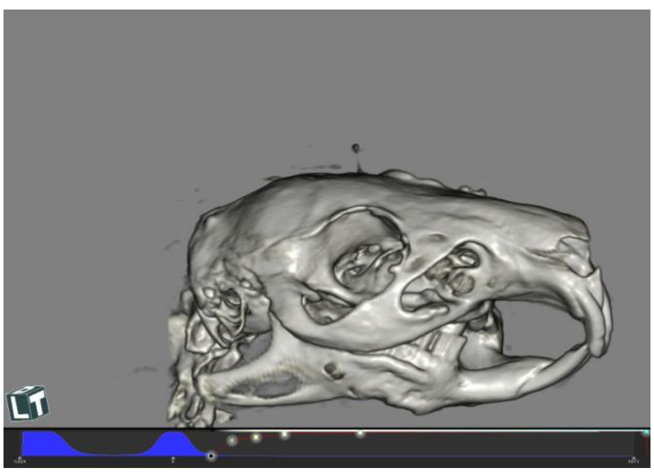


Figure 37 guinea pig skull

Figure 38 chinchilla, bullae

Before planning a CT exam a good clinical exam is mandatory to exclude concurrent problems, to determine the anesthetic risks to the patient and to ensure that CT exam is truly the best method for diagnosing the problem. In many instances further diagnostic tests have to be run before the CT scan (e.g. laboratory diagnostics, Xrays, ultrasound or endoscopy.) Based on this one has to make a list of differential diagnoses. The CT exam should be a tool to exclude or to prove one hypothesis. Without good diagnostic planning the results of a CT exam can have less diagnostic value.

Summary: The scanner is useful in neurology, pulmonology, orthopedics, endocrinology (Cushing disease), cancer (type, size , topography, staging) and exotic animal medicine. Fidex is very easy to use but we encourage the user to consult with a board certified radiologist for detailed interpretation. This is conveniently done through the DICOM send facility.

General recommendations

- Make a proper list of the differential diagnoses

- Choose the body part to be examined

- Place the body part of interest into the scanner

- Prevent patient motion by

    - using proper anesthetic techniques
    - using tape
    - control breathing

Section 3: Positioning

The general rule for good scanning is to take time to position the patient precisely and to eliminate motion artifacts.

Head:

Orientation towards the gantry depends on the size of the patient. In small patients it is preferred to place the head in the direction away from the gantry as the tube of the anesthetic machine is then outside the scanned field and does not produce unnecessary artifacts. In larger patients it is necessary to place them with the head towards the gantry. In these cases we have to tape the tubing either on top of the patient (in cases of dorsal recumbence) or to the site of the table outside the scanned field. In general it is mandatory that no metallic parts are in the tube system of the anesthetic circuit. Ventral and dorsal recumbence are both possible. Dorsal recumbence allows better immobilization of the patients head as the motion produced by respiration is largely eliminated in this position. In a patient that is respiratory compromised, the ventral recumbence can be safer. In these cases the head should be taped to the table top at the level of the nose and neck. We place a positioning device underneath the mandible to ensure a parallel position of the head with respect to the table. The central position of the head should be checked in respect to the laser pointer of the gantry. The height of the table is adjusted until the laser points to the snout. The longitudinal axis of the head should be exactly in line with the table longitudinal axis. In both positions the front legs should be pulled back out of the scanfield as the bony parts of the limb produce streaks in the scanned area.

Figure 39

Figure 40

Figure 41

Spine:

Cervical spine (C1 to T3): positioning is determined by similar principles as mentioned above (see head). In every position chosen the front limbs are pulled back towards the abdomen. In case of ventral recumbence the patient is taped to the taped to the table at the level of the mandible and the thorax to avoid respiratory motion artifacts. Again this can be done only in a respiratory and cardiovascular stable patient. Also in cases of spinal instability, luxations and fractures, ventral recumbence may be preferred, as it is considered to be safer in an anesthetized patient. In these cases the dog is taped also at the level of the head and at the level of the shoulders.

Figure 42

Figure 43

Thoraco-lumbar spine (T3-L4):

In small patients we prefer the orientation of the head outside the gantry (tubing outside the scanfield). In large dogs dorsal recumbence is the only possibility as the range of vertical motion of the table is limited and it is mandatory to place the spine as close to the center of rotation as possible (in large dogs in ventral recumbence the spine may be outside the scanfield due to the large diameter of the body). Giant breed dogs (above 50 kg) are very difficult to position for TL spinal scans in any position. In some instances we have to scan the spine in two parts, one with the patient oriented towards the gantry and one with the patient oriented outside the gantry.

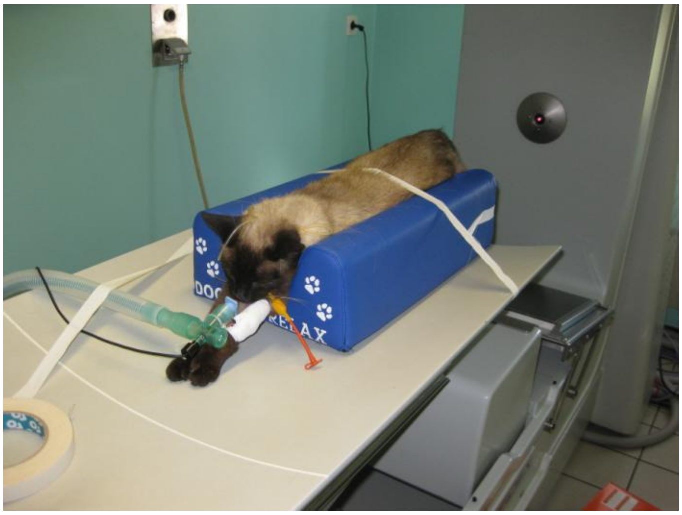


Figure 44

Figure 45

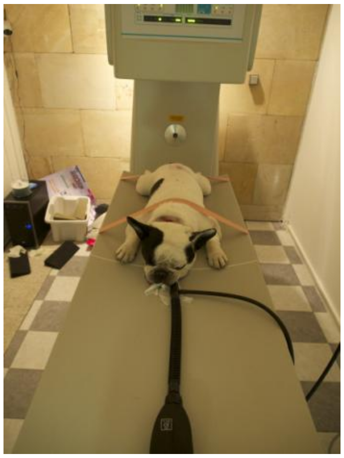


Figure 46

Lumbosacral area (L4-S):

Mostly the dorsal recumbence is preferred. If the size of the patient allows we stretch the hind limbs backwards. If this is limited due to the size of the dog and the length of the table, the pelvic limbs have to be flexed like in the "frog view" for X-rays and taped firmly to the table. The stifle joints should be pulled as far as possible caudally, to avoid interference with the scanned area of interest. In smaller breeds we prefer ventral recumbence, with the limbs pulled back and taped to the table. This is the most difficult part of the spine to be examined especially because most indications for scanning this area are in large breed dogs. In very large dogs unfortunately many artifacts appear due to thick iliac bones or interference with long bones of the pelvic limbs.

Myelographic techniques are mentioned in a Section 4: Contrast application below.

Figure 47

Figure 48

Thoracic limbs:

The orientation is in most instances toward the gantry. If the size of the patient allows, it is possible to scan both limbs together; however more artifacts can appear. The most common indications are elbow disorders. For that we can use both ventral and lateral recumbence. Lateral recumbence may be preferred in patients where only one limb has to be scanned. The limb is pulled toward the edge of the table in its center; the long bones should be oriented as much as possible parallel to the table top. As soon as the ideal position is achieved, the limb is firmly taped to the table. The main problem is the positioning of the head. In most dogs it is possible to flex the head away from the gantry and out of the field of view and tape it in this position. Proper intubation is essential to avoid respiratory compromise. Also the position of the head with respect to the C-arm must be controlled to avoid injury to the patient. Reposition the patient to scan the contra-lateral limb.

The same is true for positioning in ventral recumbence. Further stabilization of the patient's body with foam and sand bags (**at least 5cm outside the scanned field away from the gantry!**) may be necessary, as the body has to be in an upright position without tilting the limbs to the side. The disadvantage of this may be in the fact that at least the humeral bones will not be parallel. The advantage is in the possibility to scan both limbs at once.

Figure 49

Figure 50

Figure 51

For carpal scans and distal front limbs we usually use the ventral recumbence, with the paws positioned on a positioning device parallel to the table. In some dog breeds it may be impossible to flex the head backward from the gantry. In these cases ventral recumbence is also the only position achievable. Unfortunately the neck and at least a part of the skull are also included in the scanfield, which may cause further artifacts.

Figure 52

The very proximal part of the thoracic limb (humerus, shoulder and scapula) is difficult to examine in larger patients due to the large diameter of the body and superimpositions with ribs and spine. Mostly we use the ventral position, with the contra-lateral limb flexed backwards. There are certain limits in large breed dogs, as the shoulder joint will be pretty much above the center of rotation. For studies of intraarticular soft tissue lesions (e.g. biceps tendon lesions) positive contrast arthrography may be necessary (see chapter below).

Figure 53

Pelvic limbs:

The patient is placed with the pelvic limbs oriented toward the gantry. In many instances both pelvic limbs are scanned together; however, e.g. for stifle joint exams, it is preferable to scan only the site of interest and flex the contra-lateral limb cranially out of the field of view. In these cases ventral recumbence is recommended. In other indications, e.g. when hips have to be examined, the dorsal recumbence can be also used. This is also true for general pelvic scans (e.g. in pelvic factures).

Figure 54

For distal pelvic limbs, both dorsal and ventral recumbence are feasible. Contrast studies of the stifle joint are mentioned in a Section 4: Contrast application.

Thorax:

Small patients are oriented with the head away from the gantry. For thoracic scans both positions (dorsal and ventral) may be used but commonly we recommend using ventral recumbence. Ventral position is preferred especially in patients with severe respiratory compromise and cardiac disease (cardio-megaly). Also hypostatic changes in the lungs may be less pronounced in ventral than in dorsal recumbence. Again in very large dogs where the thorax is extremely deep it may be necessary to scan in lateral recumbence with the affected side upward. When needed the contra-lateral hemithorax is examined in a second scan in contra-lateral position. Again, if the dog is very large, the head at gantry side must be flexed to the lateral and fixed with tape so as to fit to the end of the table and thus to ensure that the whole lung field is in the field of view. In some instances in very large patients (over

60kg) this may be impossible. An important aspect is proper breath control during scanning of the thorax to avoid motion artifacts. This is discussed in a separate chapter (see below).

Figure 55

Figure 56

Abdomen

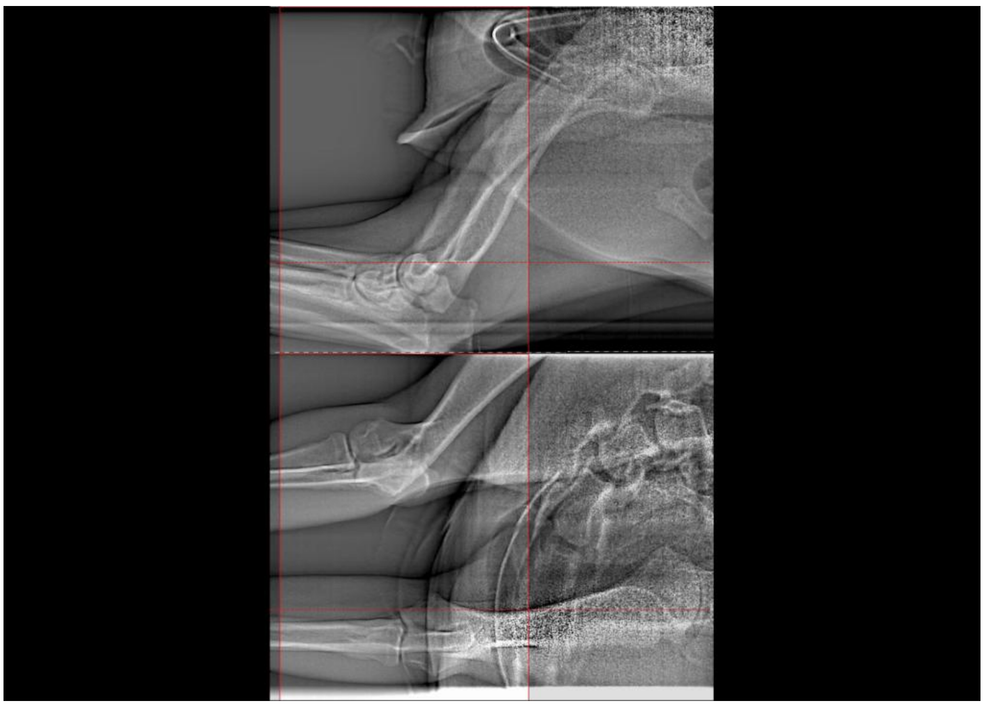
Generally the same aspects mentioned for thorax are true for abdomen, but dorsal recumbence may be more often used. Again, pelvic limbs have to be pulled out of the field of view. Sometimes it is necessary to fix the limbs in “frog position” to ensure that the whole abdomen is in the scan field. Contrast studies are discussed in Section 4: Contrast application.

Figure 57

Figure 58

Preview

Previews are necessary to ensure that the examined body parts are in the scanfield. We highly encourage the user to always do a two view preview, especially if limbs or the spinal cord have to be examined. In some instances like skull studies, one preview may be appropriate for the experienced user. In case the position is not optimal, this should be corrected and a new preview initiated. The scanfield must be defined with the help of the preview. If technically possible, the fewer body parts outside the field of view during the examination the better, as they may contribute to artifacts. Preview must be finished before IV contrast is administered.



Section 4: Contrast application

In general a native scan must be performed before any contrast application. For most indications contrast studies are absolutely mandatory. We can distinguish between

Systemic contrast applications

Systemic contrast application is used for enhance contrast of certain body parts. Contrast enhancement occurs in two ways. First, contrast medium reaches an area through a blood vessel, so that the major portion of tissue enhancement is a direct reflection of blood flow. Since most contrast agents consist of small particles they freely diffuse across endothelial walls so that the second mechanism is a reflection of vascular permeability. In other words: areas which have increased permeability of the vascular endothelium (as it is in neoplastic or inflamed tissues) have more contrast uptake.

In general, any iodinated contrast medium may be used; most commonly we prefer Iohexol or Iopamirol. Standard IV dose is 800 mg iodine/kg (in Iopamirol 350mg/ml which is more than the recommended dose of 2ml/kg), maximum volume should not exceed 60ml total in a large breed dog. It is important to place the largest possible IV cannula (with respect to the size of the patient), to be able to inject the contrast medium as fast as possible.

Typically, contrast uptake is from 30 seconds to 300 seconds after injection. This depends also on the size of the patient as well on the patient's heart rate.
One must take this into account with respect to the duration of the scan to get good contrast outcomes.

We advise timing the native scan.

For example, suppose the native scan is 3.5 minutes=210 seconds. It takes about 15-45 seconds to complete manual administration of contrast (depending on the volume administered and the size of the IV cannula); and we have to expect about 20-30 seconds for the scan to start after pressing the Start button.

Formula:

Time 0-45 sec	Give contrast and push the start button at end of injection.
Time 60sec	Scan starts
Time 90 sec	Contrast appears
Time 290 sec	End of scan
Time 380 sec	Contrast gone (except for kidneys and bladder).

Iodine contrast is finally excreted by the kidneys into the ureters. This excretion is used to visualize kidneys and the whole urinary system, useful for diagnosis of ectopic ureters, concrements in kidneys and ureters and neoplastic disease.

Figure 59

Local contrast application techniques:

Local contrast application techniques include-myelography, arthrography, retrograde cystography, and -fistulography.

Myelography:

Contrast studies of the spinal cord are essential in localizing extradural and intradural lesions as well as their possible lateralization for planning later surgical approaches. However it is considered good practice for spinal studies to first make native scans, second an IV contrast study, and at the end the myelographic techniques. In some instances the first two steps are already diagnostic and myelography is unnecessary. The principles of the technique are generally the same as in conventional radiology and the reader is referred to basic textbooks. Also we use commonly recommended contrast media. In our experience we use hypotonic contrast media (Iopamirol 200 at 0.4ml/kg) in higher doses than usually recommended in the literature.

Figure 60 myelography

Arthrography:

Punction sites are the same as recommended for radiographic studies or local anesthetic techniques. Most commonly in CT studies we use arthrography for evaluation of intraarticular structures of the stifle joint (cruciate ligament and menisci); rarely is it used in other joints (e.g. shoulder for evaluation of the biceps tendon or integrity of joint capsule). The commonly used dose is about 5ml per joint (3-8ml depending on the size of the joint). After administration the joint is extended and flexed a few times for good contrast distribution. Usually contrast stays inside the joint for a relative long time so timing of the scan is not critical.

Other contrast techniques (fistulography, cystography, etc.) follow the rules of general radiology: in CBCT scans it is important to realize that a large amount of positive contrast in the urinary bladder will produce some beam hardening artifacts. Therefore we sometimes use negative contrast cystography (air) to visualize the bladder wall; in some instances we also apply double contrast techniques (air and IV contrast media).

Section 5: Anesthesia and breath control

Principles of inhalation anesthesia commonly recommended in basic textbooks are used during CT scanning. All tubing must be free of any metallic parts to avoid artifacts. Long tubing may be necessary between patient and anesthesia machine, due to the movement of the table during scanning. For breath-holding a half-open system is preferable to open circuits, because it can be closed intermittently during breath-holding. Injection anesthesia may be also used for many indications (besides abdominal and thoracic scanning); however we discourage scanning sedated patients without intubation, especially in cases when the neck has to be flexed out of the scanned field of view. To prevent severe respiratory compromise, intubation is therefore absolutely mandatory even if injection anesthesia is used.

Figure 61 intubation is important

Breathing control:

Even small motions less than 1mm of the scanned object can cause important artifacts. For good breath control we need a very deep anesthesia in our patients. One simple way to reduce significantly breath-related artifacts in small and mid-size patients is chemical blockage using propofol. With this technique the patient is intubated after routine induction and connected to the circuit. After doing the Previews the animal is manually hyperventilated for about a minute, then a bolus of propofol is applied IV which leads to apnea for about 45 seconds. Ideally the bolus should be applied after the C-arm has rotated into the start position (about 20 seconds after actuating the CT scan), so that the breath-holding effect lasts through most of the exam. Logically this technique works for relatively short scans and is not considered ideal for scanning a large thorax which takes minutes. We recommend having the patient connected to an oxygen delivery system as it may be necessary to ventilate the patient manually between the scanning cycles.


Figure 62 manual high pressure breath control

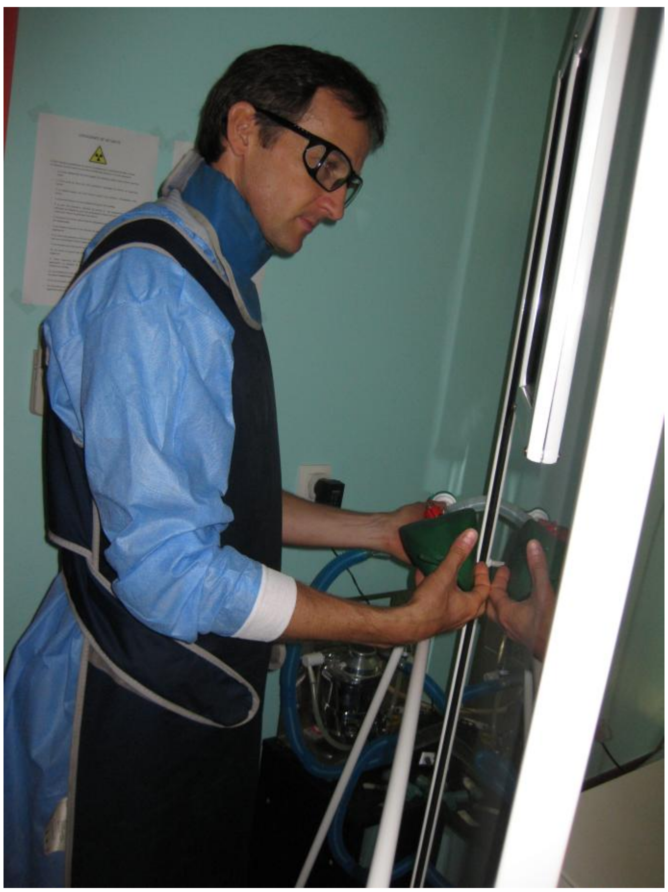


Figure 63 detail

Inhalation anesthesia

A more precise technique is based on the coaxial Bain system. The system contains a pressure valve and a bag. Once the patient was hyperventilated with isoflurane in oxygen the scanning process is started. When the C-arm is in position, the valve is kept closed during the scan cycle and the patient's lung is held in the inspiratory phase. Between the scan cycles the valve is opened and the patient quickly ventilated manually. The advantage of this technique is that the patient can be regulated in breath holding during a relatively long scan (as it is for the thorax in a medium to large breed dog) and that barotrauma of the lungs is prevented by the pressure control . A disadvantage is that the examining person must be in the same room with the patient during the whole scan; a protective lead shied is therefore necessary.

If available, the patient can also be connected to a mechanical ventilator and a closed system and the ventilator can be stopped during the scan cycles in inspiration phase. Barotrauma is possible but unusual and distant regulation may be possible without exposing personnel to radiation.

Figure 64 coaxial Bain system

Figure 65 Tube cuff insuflatio to seal the system

Section 6: Clinical examples

Head:

Ears

Case 1: Ulysse, dog, male, Kavalier King Charles Spaniel, 12kg, 10 years.
The dog was presented for pain at opening the mouth and otitis externa. **CT scan** was performed in dorsal position, head facing away from the gantry, using extended beam and two slabs **Settings:** Voltage 110kV, Current 31 mA, mAs per shot: 0.10 mAs/projection, total 37.2 mAs, reconstruction algorithm: standard.
The findings were *otitis externa* and media on the left site with a *susp. cholesteatoma* in left bulla.
Therapy: Total ear canal ablation (TECA) and lateral *bulla osteotomy* was performed and the *cholesteatoma* was removed. The dog was presented 9weeks later for a follow-up scan. The settings were the same as in the first exam. Soft tissue opacity is visible inside the bulla as well as hyperostosis of the bulla wall. **Figure 66, 67**

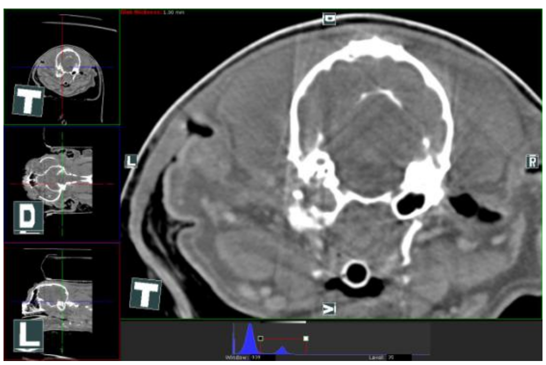


Figure 66

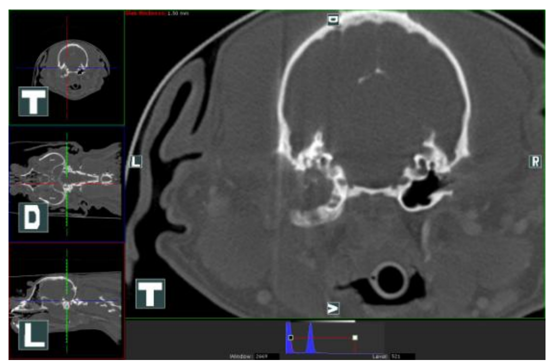


Figure 67 post OP

Case 2: Alf, dog, male intact, American Cocker spaniel, 16kg, 8years.
The dog was presented for chronic, recurrent bilateral otitis externa. On clinical exam the dog presented with head tilt to the left, otoscopy proved bilateral purulent otitis and facial paresis on the left site.
CT scan was performed. Patient was positioned in ventral recumbence with the head towards gantry. **Settings:** Voltage 110kV, mAs/shot: 0.10 mAs, total 74.5 mAs. Reconstruction kernel: bones. On the native scan bilateral otitis externa is clearly visible; both bullae are filled with soft tissue material. There is a lytic lesion on the cochlear apparatus on the left site.
Treatment: after systemic and local antibiotic therapy (based on cultivation results) a total ear canal ablation (TECA) with lateral bulla osteotomy was performed. All inflamed tissue was removed and sent for histopatology to exclude a neoplastic lesion. The dog recovered well.
Figure 68

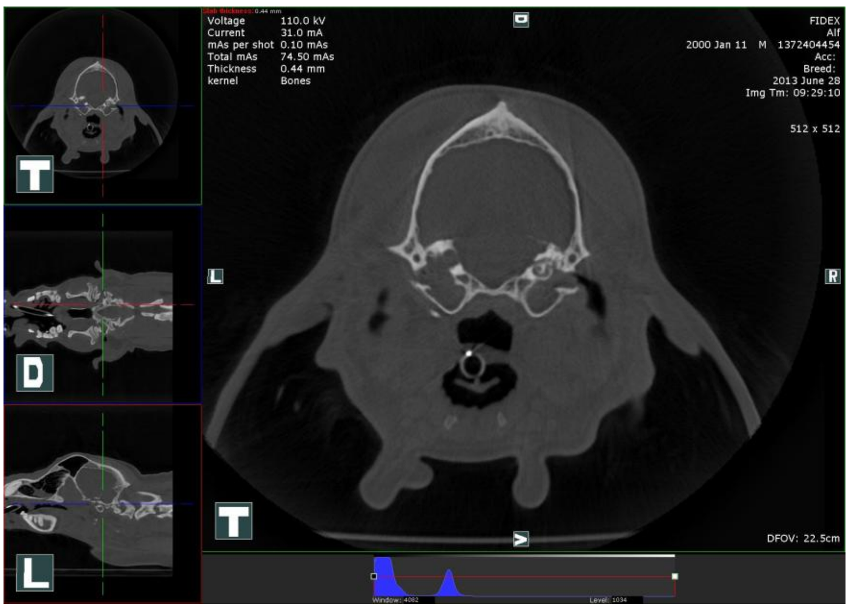


Figure 68 otitis

Case 3: Citron, cat, male cast. DSH, 3kg, 2 years
The cat was presented for intensive headshaking and sneezing with purulent discharge from both nostrils. Otoscopy proved retrotympanic fluid or mass on both sites.
CT scan was performed (native and post contrast with iomerol), patient positioned with the head outside the gantry in ventral recumbence. **Settings:** Voltage 110kV, mAs/shot: 0.06 mAs total 46.96mAs, reconstruction algorithm: standard. Both bullae are filled with material of soft tissue density; there are no changes of the bony structures.
Three weeks after conservative treatment a **follow-up CT scan** was performed (ventral recumbance, head facing outside gantry) **Settings:** Voltage 110kV, mAs/shot: 0.08 mAs total 20.48 mAs, reconstruction algorithm: standard. Only the left bulla shows soft tissue density, right bulla is clear.
Therapy: left sided ventral bulla osteotomy was performed and an aural polyp was removed.
Figure 69, 70

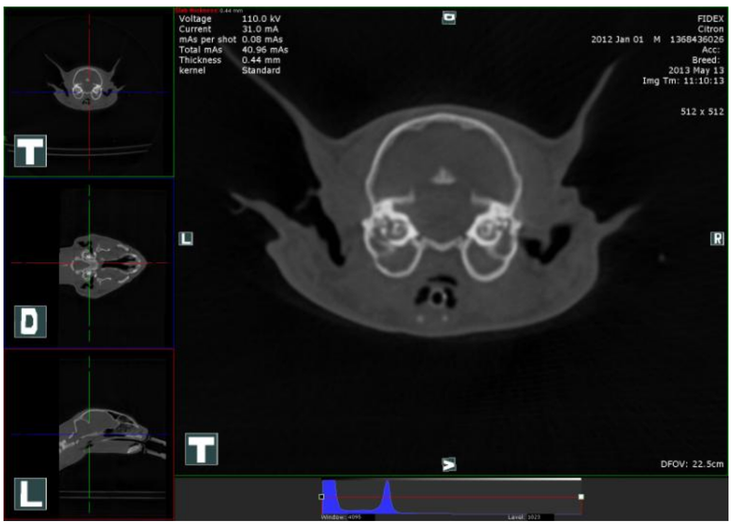
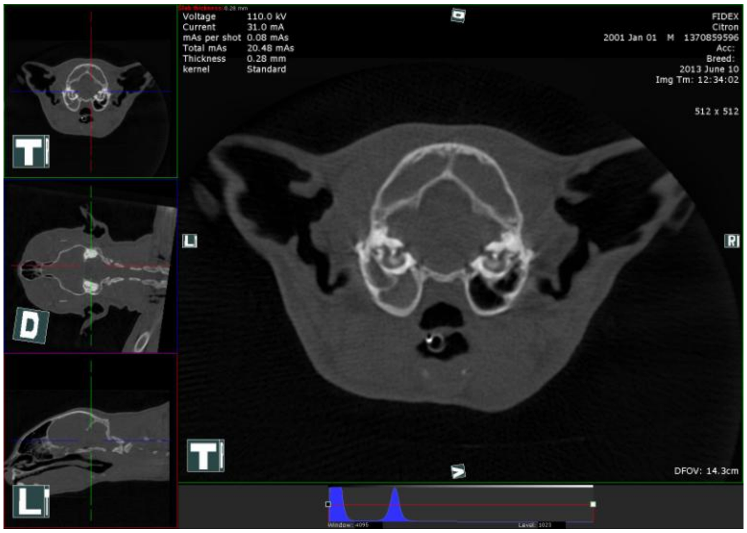


Figure 69


Voltage 110.0 kV
Current 31.0 mA
mAs per shot 0.08 mAs
Total mAs 20.48 mAs
Thickness 0.28 mm
kernel Standard
FIDEX
Citron
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Acc:
Breed:
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Img Tm: 12:34:02
512 x 512
DFOV: 14.3cm

Figure 70

Nasal cavity

Case 4: Hemi, dog, female, Bernese Mountain Dog, 48 kg, 8 years.

The dog was presented for nasal stridor and discharge. **CT scan** was performed, patient in ventral position, head facing the gantry. **Settings:** Voltage 110kV, Current 31 mA, mAs per shot: 0,15 mAs total mAs 55,8 mAs, reconstruction algorithm: standard. Pre- and post contrast studies established soft tissue mass filling the whole right nasal cavity with partial destruction of the septum. Ventrally the mass was expanding to the left nasal cavity. Left nasal cavity was also ventrally filled with mucus.

Therapy: Low grade carcinoma was diagnosed on histopathology from a biopsy. The mass was removed though dorsal rhinotomy and adjuvant radiotherapy was initiated. **Figure 71**

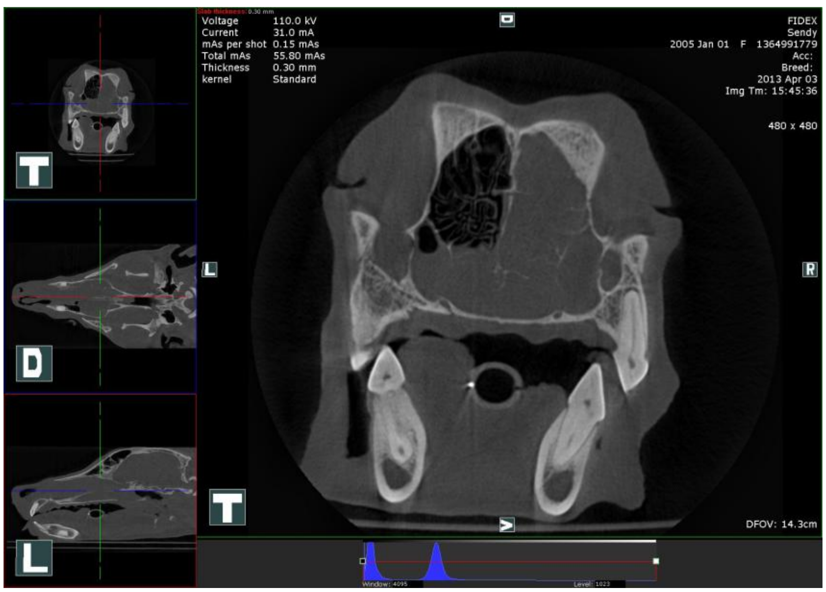


Figure 71

Case 5: Lilu, dog, female, Beauceron, 32kg, 10 years.
The dog was presented for one episode of epistaxis from the right nostril. **CT scan** was done in dorsal position, head facing toward gantry. Extended beam, 3 slabs. **Settings:** Voltage 110kV, Current 31 mA, mAs/shot: 0.11 mAs, total 56.32mAs, reconstruction algorithm: standard. Standard contrast study. The major finding was a soft tissue mass in the caudal part of the right nasal cavity with erosion of the cribriform plate. The mass was removed surgically by transoral approach. Histopatology proved the tumor to be adenocarcinoma. **Figure 72, 73**

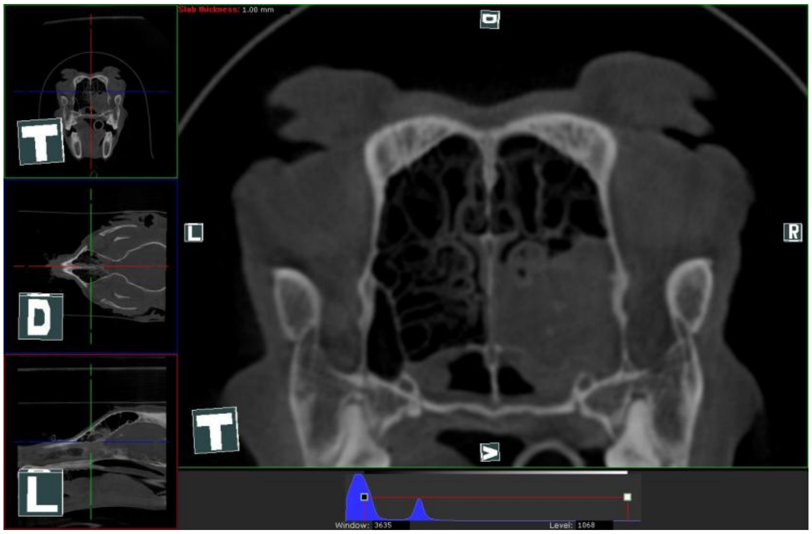


Figure 72

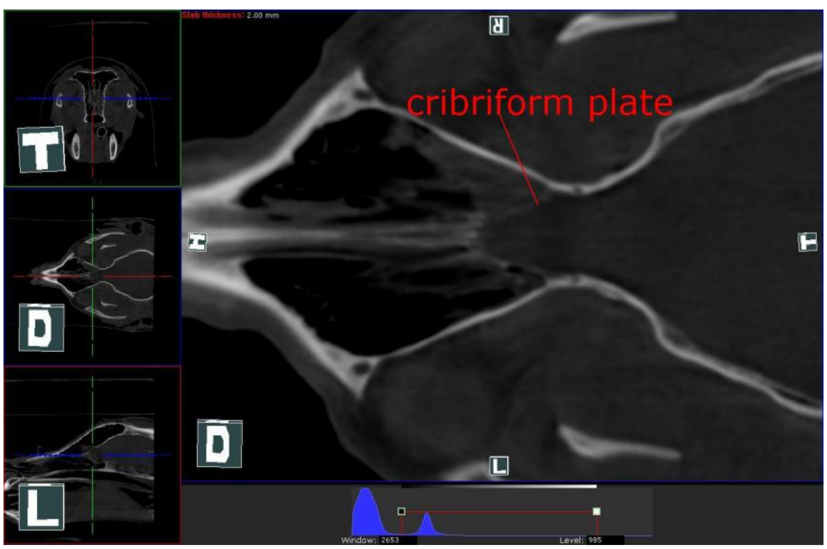


Figure 73

Case 6: Clarence, cat, female spayed, DSH, 5kg, 12years old

The main complaint was bilateral nasal discharge. CT scan of the head was performed with the animal in dorsal recumbence, head facing away from the gantry. Half beam, two slabs. **Settings:** Voltage 110kV, Current 31 mA, mAs/shot: 0.11 mAs, total 40.92 mAs, reconstruction algorithm: standard. Standard contrast study.

Bilateral rhinitis discretely destructive was found in both nasal cavities, consistent with a non-specific inflammatory (allergic, lyphoplasmatic or eosinophilic) or infectious process. Conservative therapy was successful. **Figure 74**

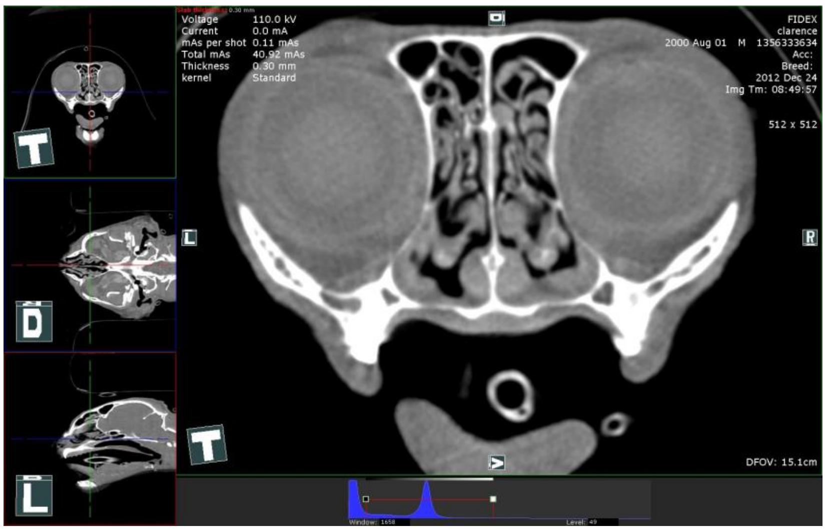


Figure 74

Oral cavity

Case 7. Oasis, dog, male, English Cocker Spaniel 14 kg, 15 years old

The owner presented the dog for deformation of the dorsum of the nose. The **CT study** was made in dorsal position with the head facing towards the gantry, with half beam, tree slabs.

Settings: Voltage 110kV, Current 31 mA, mAs/shot: 0.08 mAs , total 20.48 mAs, reconstruction algorithm: standard. Standard contrast study.

Findings were multiple dental abscesses and denuded tooth roots with multiple fistula formation into both nasal cavities. Extraction was performed on the affected teeth together with standard conservative management. **Figure 75, 76**

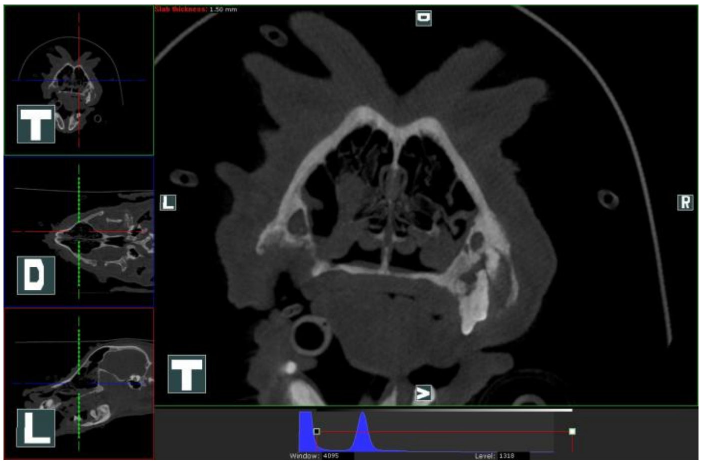


Figure 75

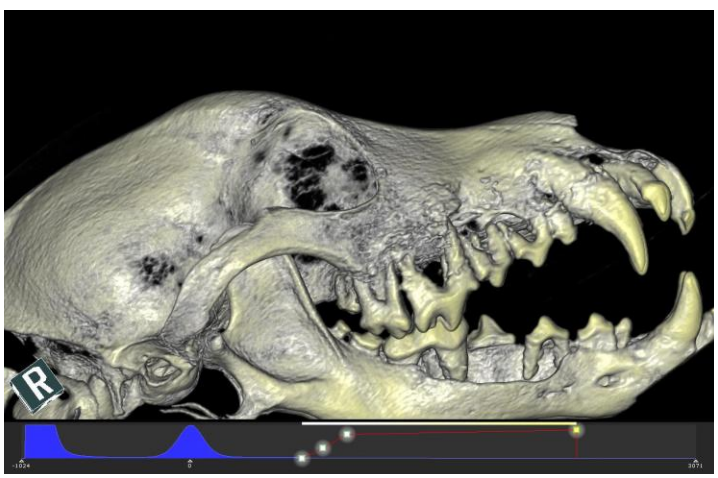


Figure 76

Case 8. Berunka, female unspayed, Engl. Bullmasiff, 53 kg, 6 years

The patient was referred one month after right sided subtotal hemimandibulectomy, due to mandibular fibrosarcoma. On oral exam a mass was visible caudal to the remaining canine tooth of the left hemimandibule. **CT scan** was performed with the patient in ventral position, head facing the gantry. **Settings:** Voltage 110kV, Current 31 mA, mAs/shot: 0.15 mAs, total 75mAs, reconstruction algorithm: standard. Native scan. Severe bone destruction with bone lysis and resorption was found from the remaining right incisors, crossing the symphisis up to the first molar on the left site.

Therapy: on biopsy a presence of the recurring sarcoma was confirmed and a subtotal right-sided hemimandibulectomy up to the level of M2 was performed. Adjuvant chemotherapy was initiated. **Figure 77, 78, 79**

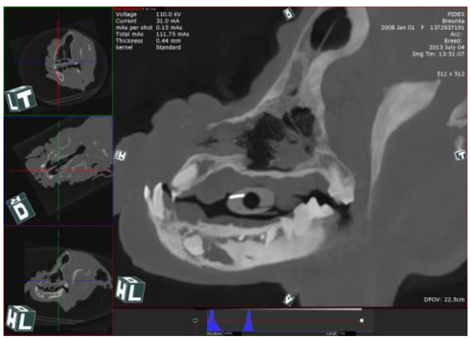


Figure 77

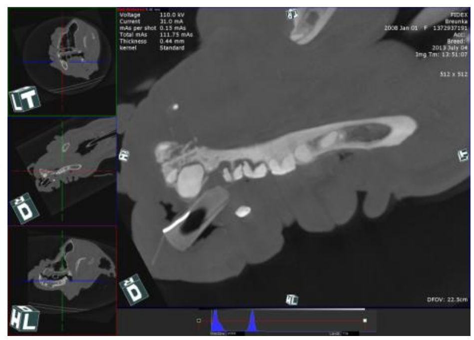


Figure 78

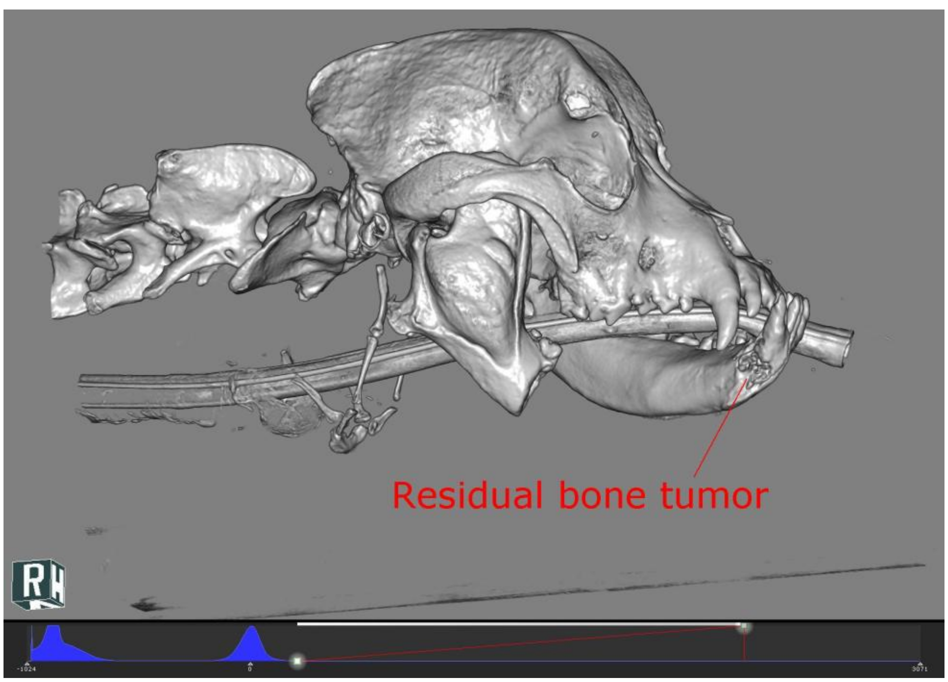


Figure 79

Brain:

Case 9: Haribo, dog male, Bernese Mountain Dog, 38kg, 1 year old.

The main complaint in this patient was atrophy of temporal muscle and enophthalmy and decreased sensitivity of skin and lip of the all on the right side of the face. **CT scan** was performed in dorsal recumbence, head facing the gantry. Extended beam, 4 slabs **Settings:** Voltage 110kV, Current 31 mA, mAs/shot: 0.10mAs, total 51.20 mAs, reconstruction algorithm: standard. Standard contrast study. The major finding was an extra-axial mass with diffuse thickening of the mandibular branch of the trigeminal nerve. Further therapy was declined. **Figure 80**

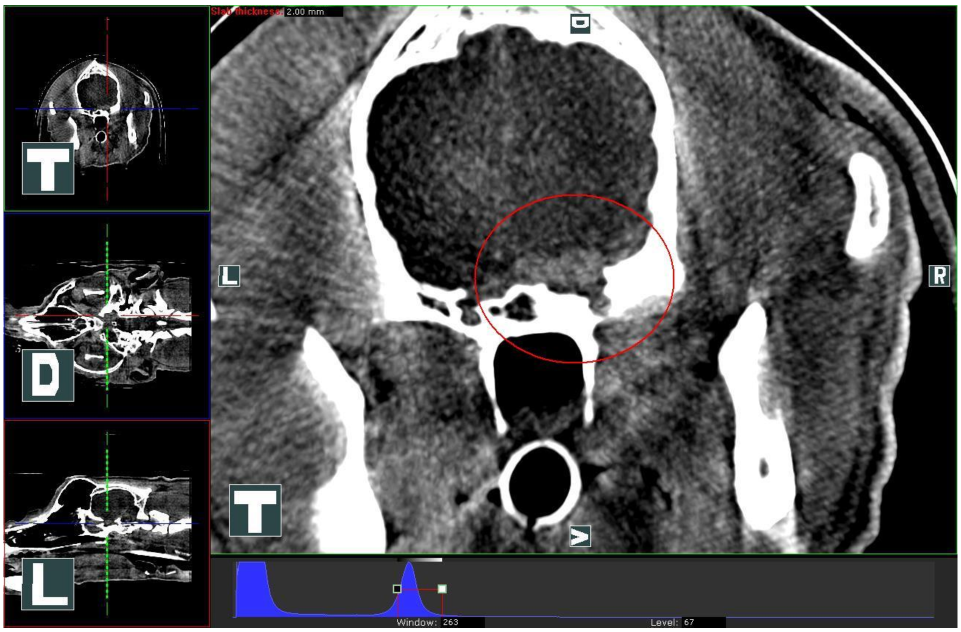


Figure 80

Case 10: Kahina, dog, female, American Staffordshire, 21 kg, 11 years
The dog was presented for behavioral changes. CT scan was performed in dorsal recumbence with the head facing away from the gantry. Extended beam four slabs. **Settings:** Voltage 110kV, Current 31 mA, mAs/shot: 0.10mAs, total 51.2 mAs, reconstruction algorithm: standard. Standard contrast study. We can see a marked midline shift in the cerebrum due to intraaxial mass in the right hemisphere. The possible differential diagnoses were glioma, oligodendroma or astrocytoma. **Figure 81**

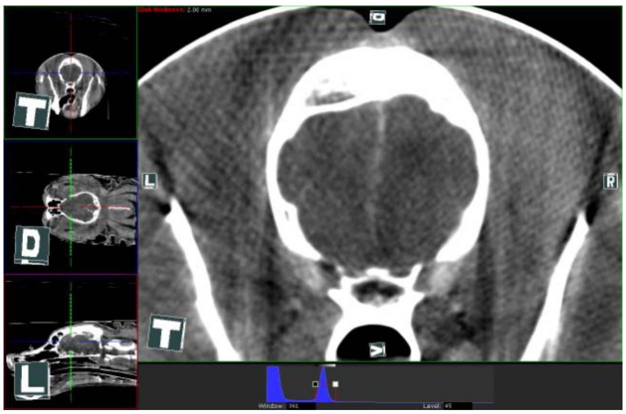


Figure 81

Case 11: Tigro, cat, male castrated, DSH, 8kg, 11 years
Anamnestically the cat was treated for diabetes mellitus not responding to insulin therapy. Serum growth hormone was increased. A **CT scan** was performed with the cat in ventral position with the head facing away from the gantry. Extended beam, two slabs. **Settings:** Voltage 110kV, Current 60 mA, mAs/shot: 0.11 mAs, total 81.95 mAs, reconstruction algorithm: standard. Standard contrast study. Results were on normal brain study, with the pituitary gland discretely increased. The finding was consistent with acromegaly and pituitary adenoma. The cat was treated with radiotherapy. **Figure 82**

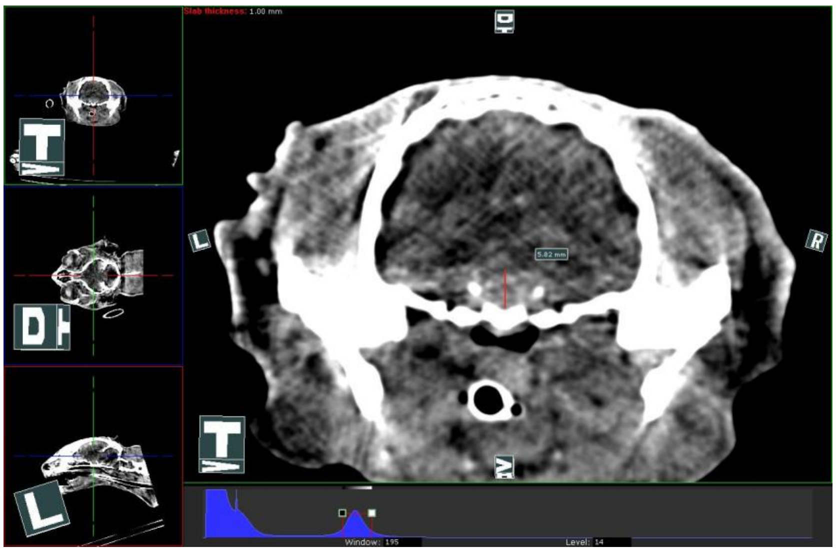


Figure 82

Spine

Case 12: Johnny, dog, male, Yorkshire terrier, 4.5kg, 9.5years

The dog was presented for hind limb ataxia progressing to paraparesis during the last days. **CT scan** was initiated. Patient was positioned in ventral position, head facing away from the gantry. **Settings:** Voltage 110kV, mAs/shot: 0.08 mAs, total 46.96mAs, reconstruction algorithm: bones. On the native scan a lytic bone lesion with bone resorption of the vertebral arch was visible between TH 12 and TH13. In the same area a contrast enhanced mass was noticed invading between the two vertebrae from dorsal. A myelogram was performed (occipital and lumbar application), which confirmed an extradural mass growing dorsally into the spinal canal, compressing the spinal cord dorso-laterally from the right site. A soft tissue spinal tumor was suspected.

Therapy: hemilaminectomy as performed for palliative surgery. Most of the tumor mass was removed via hemilaminectomy and the patient was set on conservative management. Histologically the tumor was classified as meningioma. Symptoms recurred 4 months after surgery and euthanasia was performed. **Figure 83, 84, 85**

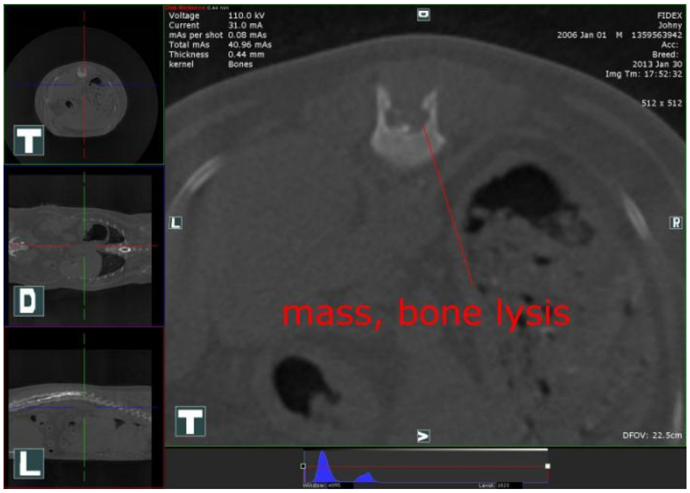


Figure 83

Figure 84

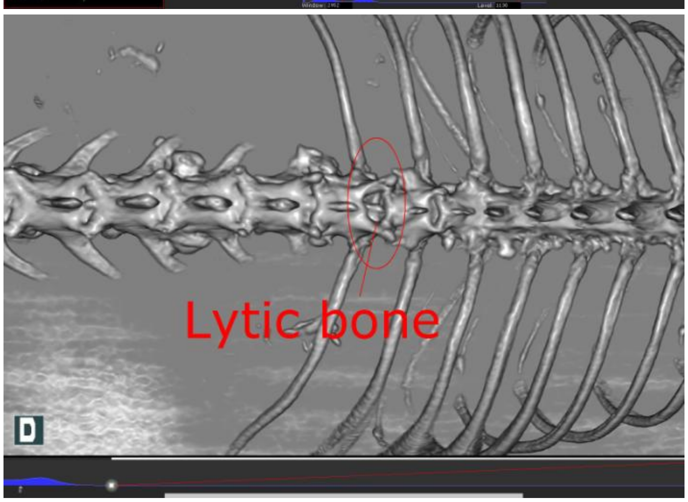


Figure 85

Case 13: Triskelle, dog, female, Bishon, 9kg, 11 years
Anamnesis: Right-sided hind limb lameness since three weeks without orthopedic findings, with marked muscle atrophy of the affected limb. **CT study** of the spine was performed. The patient was positioned in dorsal recumbence with the head facing away from the gantry. Extended beam, 4 slabs. **Settings:** Voltage 110kV, mAs/shot: 0.11 mAs,   total 81.95 mAs, reconstruction algorithm: standard. Standard IV contrast study.
Results: Intramedulary mass at the level of L5, lateralized to the right, massive neurogenic atrophy of the ypsilateral pelvic limb. This mass was consistent with a neoplastic process, such as glial tumor, metastatic disease or lymphoma. Palliative therapy was initiated, two months later euthanasia was performed due to worsening of the symptoms. **Figure 86**

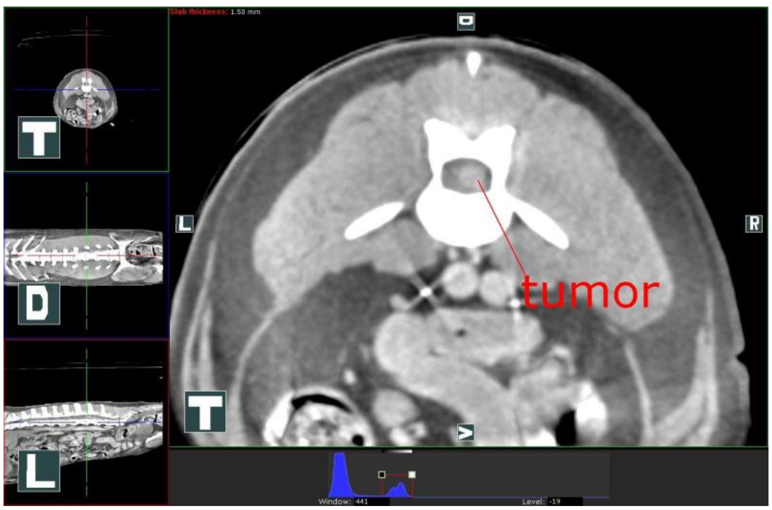


Figure 86

Case 14: Leeloo, cat, female spayed, DSH, 4kg, 3.5 years

The cat was brought in due to acute onset of hemiparesis of the left hind limb. The signs appeared two weeks ago and the owner noticed a bleeding fistula on the back at the same time. A native **CT scan** was performed with the cat in ventral position the head facing outside the gantry.   **Settings:** Voltage 110kV, mAs/shot: 0.08 mAs, total 20.48 mAs, reconstruction algorithm: bones. A hyperdense foreign body (bullet) was found dorso-lateral to the arch of L4. A small impression fracture was noticed at the contact area. **Therapy**: the bullet was removed surgically and a decompression of the spinal cord was achieved by carefully removing the impressed bone fragments. The cat recovered uneventfully after physiotherapy. **Figure 87**

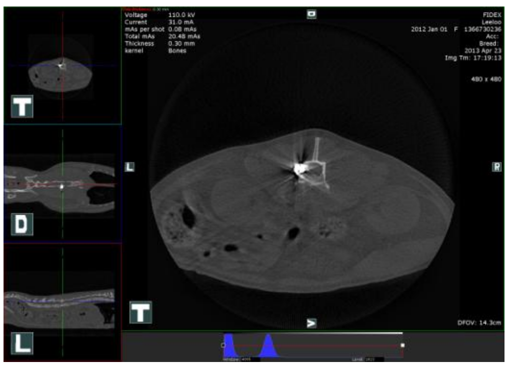


Figure 87

Case 15: Bara, dog female spayed, beagle, 15kg, 10 years
The dog was presented with a history of stiff gait and painful vocalization with acute onset one week ago. CT scan of the neck was indicated. The patient was positioned in ventral recumbence with front limbs pulled back; the head was facing towards the gantry. **CT Settings:** Voltage 110kV, mAs /shot: 0.10 mAs, total 51.20 mAs, reconstruction algorithm: bones.
On the native CT study a mass was noticed in the vertebral canal between C3 and C4. A CT myelography was performed with same settings and confirmed a ventral extradural lesion compressing the spinal cord. There was a decent lateralization to the right.
Therapy: a ventral slot was performed between C3-4, herniated disc material was removed and the dog recovered uneventfully. **Figure 88**

Figure 88

Case 16: Deborah, dog, female spayed, Rhodesian Ridgeback, 28kg, 2years
The dog was referred with a history of acute back pain and fever. The problems first appeared about two weeks after the bitch was spayed. A **native CT scan** was performed with the dog in dorsal recumbence the head facing outside the gantry. **Settings:** Voltage 110kV, mAs/shot: 0.15 mAs, total 76.80mAs, reconstruction algorithm: bones. A collapse of the disc space was noticed between Th 12 -13. There was also marked end plate lysis on both sides of the disc space. A myelography was performed with the same settings. It did not confirm spinal cord compression. Conservative management of disco-spondylitis was initiated based on the findings. Two months later the patient was presented for a follow-up CT scan. Positioning was the same as in the first scan. **Settings:** Voltage 110kV, mAs/shot: 0.15 mAs, total 38.40 mAs, reconstruction algorithm: bones. A major progression of bone resorption was noticed with total collapse of the intervertebrate space and lytic changes in the body of Th13.

Therapy: After curettage of the abscessed vertebral body followed by bone grafting a vertebral fusion was performed with a SOP-plate between TH 10 and L1. The dog recovered uneventfully.

Figure 89, 90

Figure 89

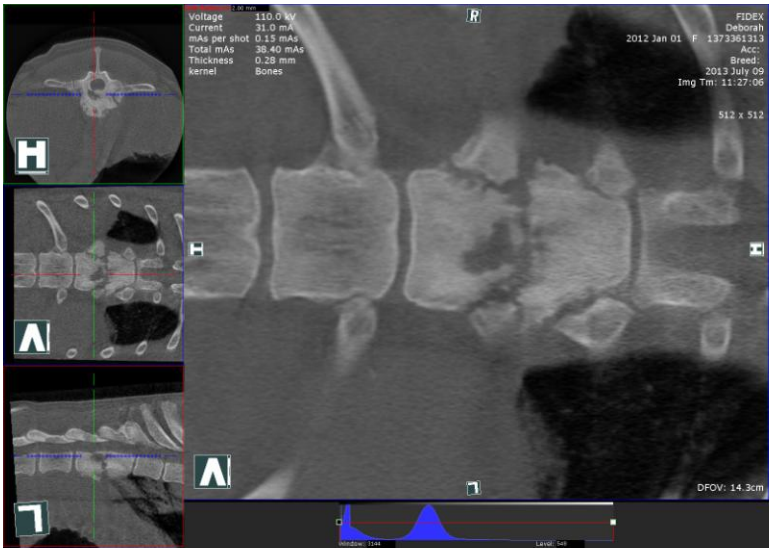

2.00 mm
Voltage 110.0 kV
Current 31.0 mA
mAs per shot 0.15 mAs
Total mAs 38.40 mAs
Thickness 0.28 mm
kernel Bones
R
FIDEX
Deborah
2012 Jan 01 F 1373361313
Acc:
Breed:
2013 July 09
Img Tm: 11:27:06
512 x 512
DFOV: 14.3cm

Figure 90

Orthopedic disorders

Case 17: Cenda, dog, male, Jack Russell Terrier, 7kg, 4years

The dog was presented after being hit by car and showed a non-weight bearing lameness on the left pelvic limb. Pain was localized in the tarsal joint with some crepitation. Xrays were inconclusive. **CT scan** was performed in ventral position, head facing away from the gantry, pelvic limbs extended caudally. Half beam, two slabs. **Settings:** Voltage 110kV, Current: 31 mAs, mAs/shot: 0.08 mAs, total 20.48 mAs, reconstruction algorithm: bones. A transverse, minimally dislocated fracture in the body of the talus was diagnosed, with a small chip fragment medially. Osteosynthesis with 2.0mm lag screw and pining was performed and the dog recovered uneventfully. **Figure 91, 92**

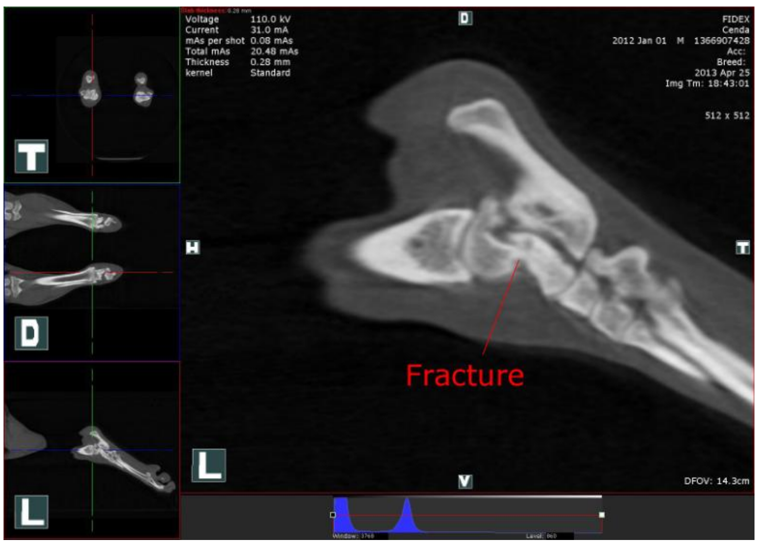


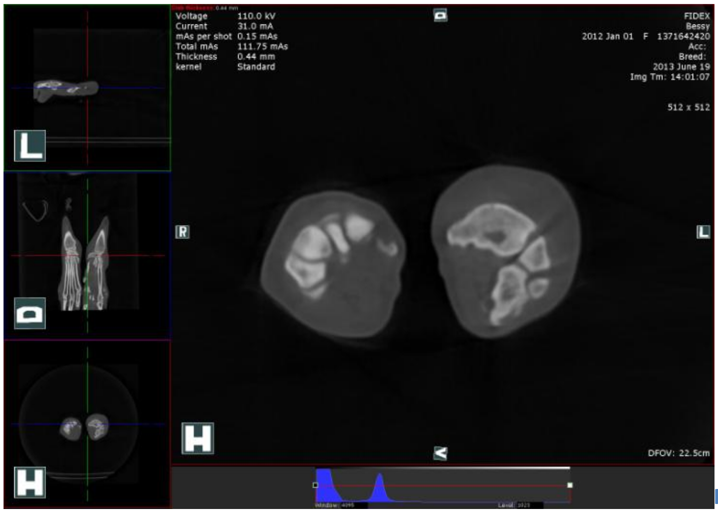
Figure 91

Figure 92

Case 18. Bessy, dog, female spayed, Golden Retriever, 40kg, 8 years
The main complaint was a long-lasting intermittent left front limb lameness with carpal swelling and pain on flexion of the carpus. During the last weeks the lameness progressed to a non-weight bearing lameness. **CT scan** was performed in ventral position with the head flexed backward, away from the field of view, with the limbs extended towards the gantry. Extended beam, 3 slabs. **Settings:** Voltage 110kV, Current: 31 mAs, mAs/shot: 0.15 mAs, total 111.75 mAs, reconstruction algorithm: bones. Multiple cystic lesions were represented inside the radial carpal bone and distal radius; there was also some decent periosteal proliferation in the III and IV metacarpal bone. Osteomyelitis was suspected based on cytologic results. After a period of conservative management a pancarpal arthrodesis with a hybrid plate was performed and the dog recovered. **Figure 93, 94, 95**

Figure 93

Figure 94


Voltage 110.0 kV
Current 31.0 mA
mAs per shot 0.15 mAs
Total mAs 111.75 mAs
Thickness 0.44 mm
kernel Standard
FIDEX
Bessy
2012 Jan 01 F 1371642420
Acc:
Breed:
2013 June 19
Img Tm: 14:01:07
512 x 512
R
L
DFOV: 22.5cm
Figure 95

Case 19. Steppe, dog male, Bernese Mountain Dog, 38kg, 7 months
Presented for front limb lameness, pain was localized to the elbow. X-ray was inconclusive. **CT scan** was performed in lateral position with the head flexed backward, away from the field of view, with the limb extended towards the gantry. Extended beam, 2 slabs. **Settings:** Voltage 110kV, Current 31 mA, mAs/shot: 0.10 mAs, total 51.20 mAs, reconstruction algorithm: bones. There was marked step formation with radio-ulnar incongruity. Proximal ulna showed a marked subchondral sclerosis and a large apical fragment of the medial coronoid process. A kissing lesion was found on the medial humeral condoyle. Arthroscopic treatment with fragment removal was performed. **Figure 96, 97, 98**

Figure 96

Figure 97

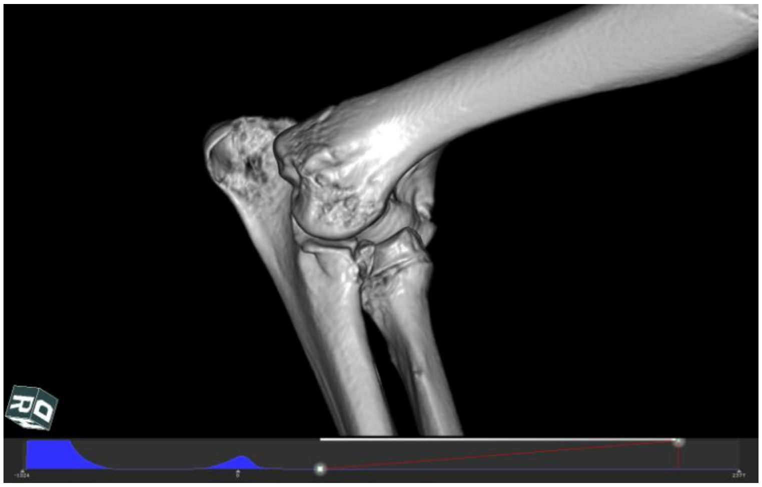


Figure 98

Case 20: Gipsy, dog, female American Staffordshire terrier, 2 years 25kg
Dog was presented for left hind limb lameness with pain localized to the knee joint. The cranial drawer sign was negative. **CT scan** was performed in dorsal position, with the head facing away from the gantry. The contralateral leg was flexed cranially. Extended beam, 2 slabs. **Settings:** Voltage 110kV, Current 60 mA, mAs/shot: 0.25mAs, total 128 mAs, reconstruction algorithm: standard. Arthrography with 5ml Iopamirol 350 was performed. The result was a contrast infiltration in the central part of the cranial cruciate ligament, consistent with partial rupture of the CCL. Menisci were considered to be normal. Surgery was initiated based on these findings.
Figure 99, 100

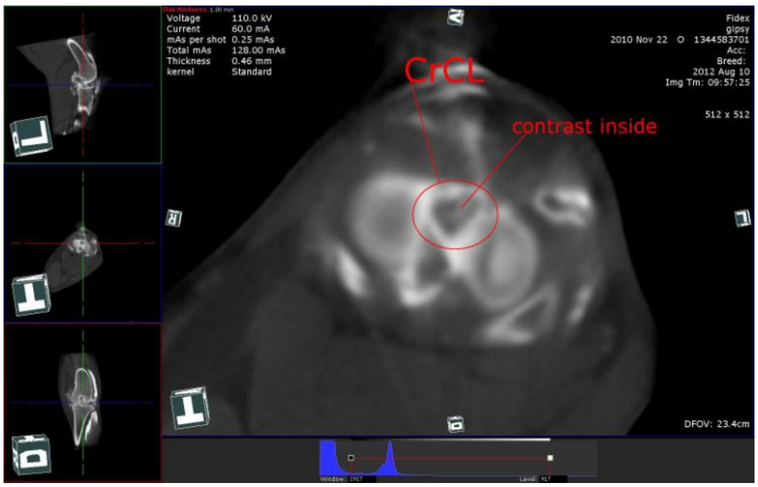


Figure 99

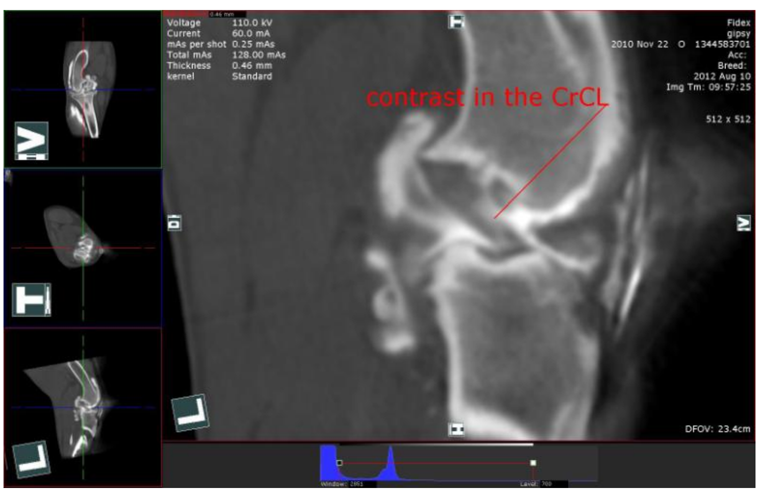


Figure 100

Skin and Andexa

Case 21: Scooby Doo, cat, male castrated, Main Coon, 6 years, 9kg
Owner noticed a fast growing mass on the left hind limb caudal and directly below the stifle joint. Cytological samples were suggestive for fibrosarcoma. **CT scan** was performed with the cat in ventral position, head facing outside the gantry with the hind limbs extended caudally. Full beam, three slabs. **Settings:** Voltage 110kV, Current 60 mA, mAs/shot: 0.08mAs, total 20.48 mAs, reconstruction algorithm: standard with contrast. There was a decent contrast enhancement of the mass with decent infiltration to the gastrocnemius muscle and surrounding subcutis. Based on the infiltrative nature of the tumor, amputation of the limb was performed. **Figure 101**

Figure 101

Thorax:

Case 22: Leon, cat, male castrated, DSH, 5kg, 14 years old
The referring veterinary surgeon removed an enlarged lymph node that was diagnosed as hemangiosarcoma. He requested a **CT scan** for exclusion of metastatic spread. The patient was positioned in dorsal recumbence, head facing outside the gantry. Extended beam, five slabs.
Settings: Voltage 110kV, mAs/shot: 0.08 mAs, total 29.76 mAs, reconstruction algorithm: standard. Standard contrast study. Multiple tissue nodules scattered in the lung consistent with metastatic pulmonary disease metastasis were found. Granulomateous disease was less probable. There was a consolidation in the left lobe probably associated with bleeding. Further treatment was performed at the referring veterinary service. **Figure 102**

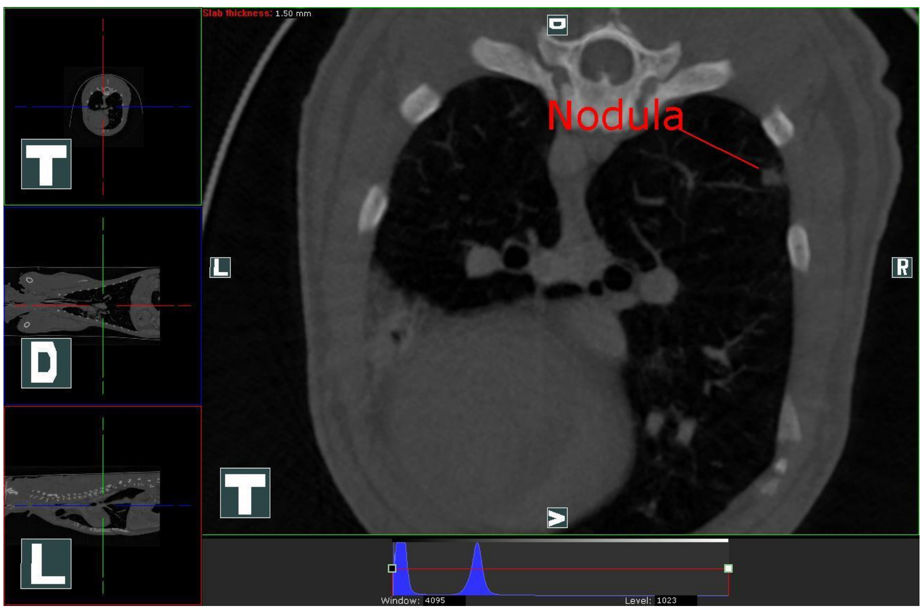


Figure 102

Case 23: Justy. Dog, female spayed, Schnauzer, 10kg, 12 years

The dog was presented for acute onset of coughing. Radiographic exam was inconclusive, so a CT scan was performed. The dog was positioned in ventral recumbence with the head facing away from the gantry. **Settings:** Voltage 110kV, mAs/shot: 0.08 mAs, total 59.60mAs, reconstruction algorithm: chest. The scan confirmed a large contrast enhanced mass in the caudal aspect of the right lung field dorso-laterally. A fine-needle biopsy confirmed the diagnosis of bronchoalveolar carcinoma. Based on the CT findings the tumor was considered inoperable. A few weeks later the patient was euthanized for severe respiratory distress. **Figure 103, 104**

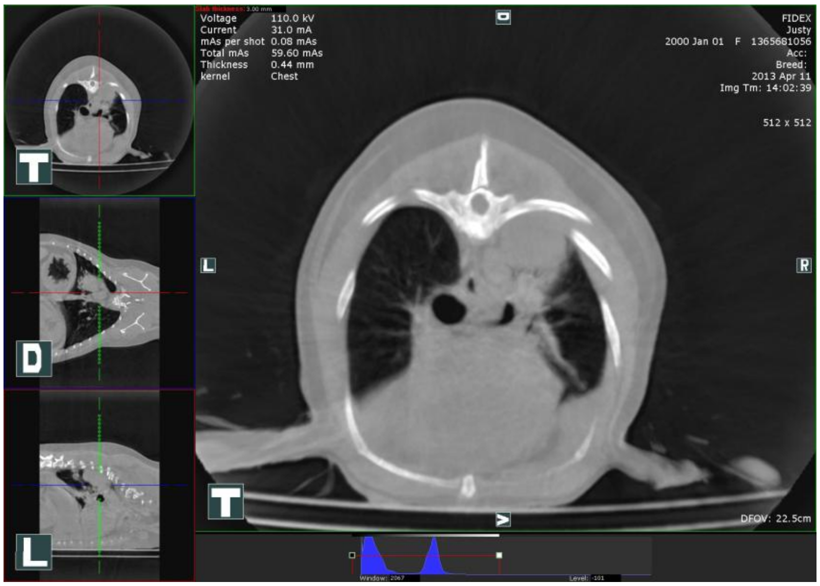


Figure 103

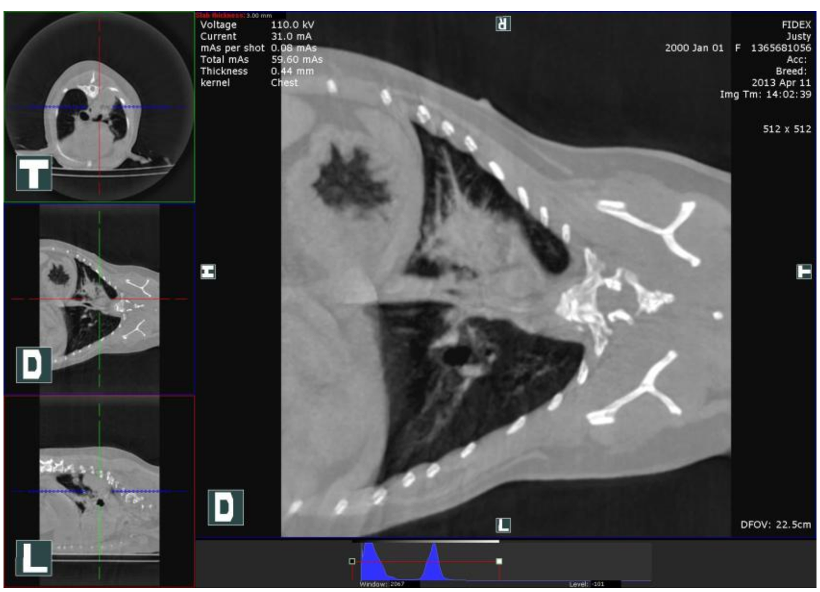


Figure 104

Case 24 : Jusquienne, cat, female spayed, DSH, 4kg, 15 years old
Mammary adeno-carcinoma staging was performed in the patient. Therefore a CT scan was indicated for the lung study. The cat was positioned in ventral recumbence, head facing away from the gantry. Extended beam, 4 slabs. **Settings:** Voltage 110kV, Current 60 mA, mAs/shot: 0.11 mAs, total 56.32 mAs, reconstruction algorithm: standard. Standard contrast study. Multiple small metastases were diagnosed in both lung fields. **Figure 105**

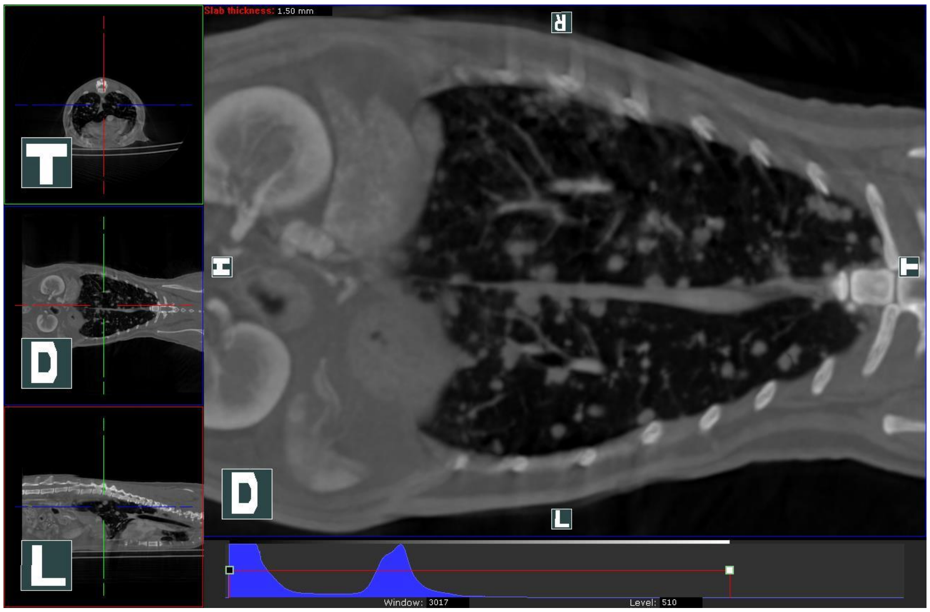


Figure 105

Abdomen:

Case 25: Cheyenne, dog, female spayed, Foxterrier, 9kg, 4 years.
Anamnestically the dog was spayed with one year, the owner complaint was, that the bitch is getting in heat again. **CT scan** was performed with the patient on dorsal position with the head facing outside the gantry. Extended beam, four slabs. **Settings:** Voltage 110kV, Current 31 mA, mAs/shot: 0.11 mAs, total 81.95 mAs, reconstruction algorithm: standard with standard contrast study. The ovarial remnant can be seen on the left site caudal to the left kidney. Based on the CT findings the remnant was removed surgically. **Figure 106**

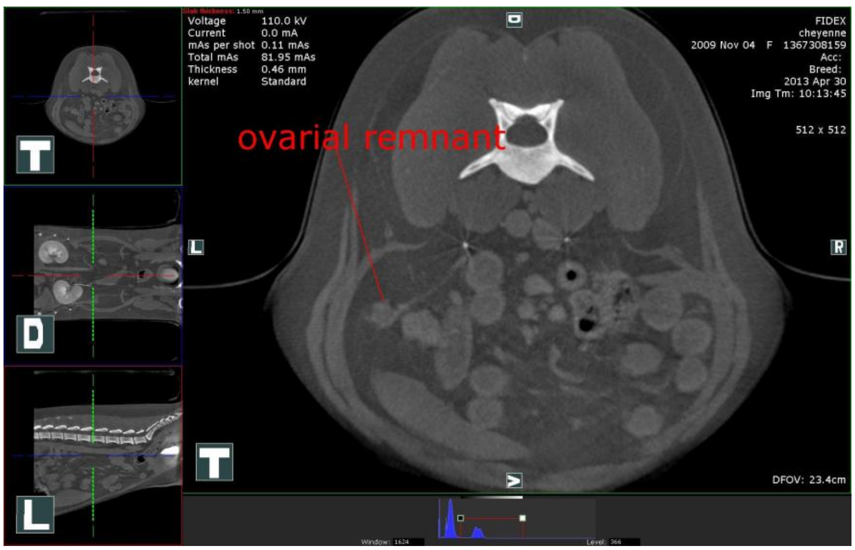


Figure 106

Case 26: Choupette, ferret, female, 1.5 kg, 4 years
At one year ovariohysterectomy was performed. After two moths the owner noticed changes of the hair coat on the tail. CT was indicated to check the adrenal glands. The animal was positioned in dorsal recumbence with the head facing away from the gantry. Full beam, 4 slabs.
Settings: Voltage 100kV, Current 35 mA, mAs/shot: 0.1mAs, total 74.50 mAs, reconstruction algorithm: standard. The size of the adrenal glands is considered to be normal, both adrenal glands could be visualized. **Figure 107, 108**

Figure 107

Figure 108

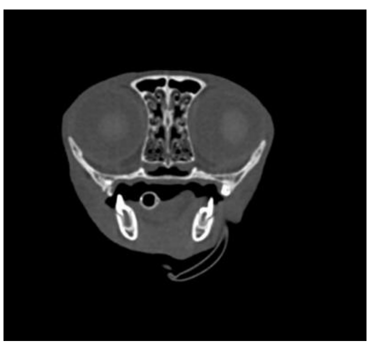
Appendix: More technical information

Slice Visualization: W/L, slab, measurement

The normal way to look at CT images is to scroll through slices. CBCT machines typically produce thin slices of 0.2mm to 0.5mm thickness, so there are a large number of slices to study. Depending on content, window and level (or, contrast and brightness) will be adjusted to give the best visual impression. For example, brain images have to be viewed with a smaller window than bone images. CBCT slices are DICOM objects conforming to the same conventions as slices produced by human CT scanners.

Since CBCT includes precise calibration of the scanner geometry, length measurements in CT images are accurate. There is no magnification or distortion.

CBCT produces isotropic images, meaning the voxels in the image are cubic. This allows display of the image in all planes without loss of resolution, as big advantage over fan-beam CT machines with their thick slices. The display of cuts through the volume other than axial slices is called MPR for multi-planar reformat. Very common are sagittal and coronal cuts. Display of joint images (elbows, knees) requires so-called oblique or double-oblique cuts, which can be easily obtained.



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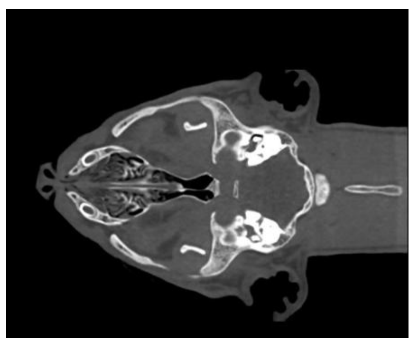

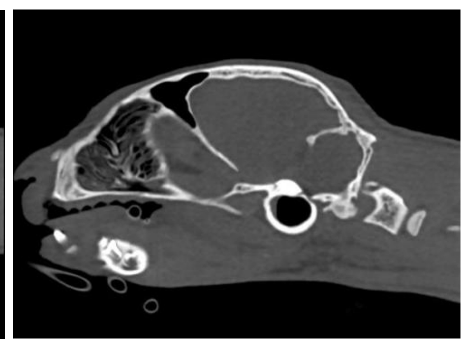

Figure 109 Figure 110 Figure 111

A very intuitive form of visualization is volume rendering, where each voxel is given an artificial color, transparency and sometimes light sources and reflectance. The VR images are often lifelike and provide direct 3-D information useful for surgeons and also for client education.

Figure 112

a. Design criteria for FIDEX

(1) Size of the FOV: diameter, scan range, scanner size, patient table size:

The size of the scanner is essentially determined by the size of the measurement field (also called field of view), and that must be chosen to accommodate the largest patients under consideration. For companion animals, one has to think about abdominal or thorax scans of dogs, so the diameter needs to be of the order of 25cm.

Scan range is the coverage along the axis of rotation. In order to image a complete thorax, the range should be about 50cm. Scan range can be achieved by volume stitching in case of a stop-and-shoot design, or through helical scanning. In either case, the patient table must be motorized to position the patient precisely along the z-axis, and it must be long enough to allow stretching out the animal. Therefore, table length is typically 1.6m or so.

The scanner itself can be quite compact. Typical width is about 1.5m, and length is a bit more than 2.5m. This is considerably smaller than a human CT scanner which must accommodate patients up to 450 lbs, >50cm diameter and scan range up to 2m.

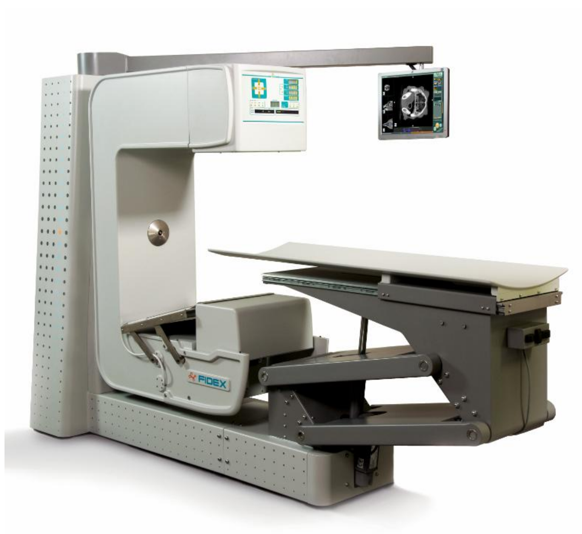

Figure 113

(2) Technique, dose, contrast, tube heat load

Most CT scanners keep the kV's at 100kV to 120 kV. This provides good penetration of biological material, the attenuation coefficient is reasonably independent of the x-ray spectrum, and contrast between soft tissue and bone is excellent. At a given kV setting, it is therefore sufficient to characterize the dose applied in mAs (the current-time product). A human CT scanner uses typically 200 mAs per turn. Assuming 0.5 sec rotation time, this translates into 48 kW at 120 kV. Faster (cardiac) scanners sometimes provide twice the power.

Typical CB-scanners rotate slower than human scans, so the instantaneous x-ray power can be reduced accordingly. X-ray power rarely exceeds 3.5 kW which is good news for tube lifetime and installation cost. Add to this the much larger solid angle captured by the cone beam geometry, and one ends up with a 10-fold savings in energy expended on x-rays for CBCT compared to slice-based CT. The tube heat load of a CBCT tube is therefore only 5% to 10% of that required for a slice-based scanner for medical use.

The patient dose, however, must be comparable in order to achieve comparable image quality. What counts is the number of photons going through each voxel of the 3-D image.

(3) Spatial resolution

CBCT has the potential of much higher spatial resolution, which is a big plus for animal scanning. The small bones in the inner ear of a cat are much smaller than the smallest structures to be visualized on humans. The technical background is that CB CT detectors (flat panels) have small pixels (typically 0.254mm) and the low-power tube has a small focal spot (0.5mm). It should be kept in mind, however, that the highest spatial resolution can only be achieved through the application of very sharp convolution kernels, and that is a cause of image noise. So high resolution is only done for bone work with high contrast. Soft tissue images are usually smoothed out to 1mm or more.

In the choice called "**algorithms**", Fidex combines image sharpness or smoothing with other corrections. Algorithms include **standard**, **bones**, **soft tissue**, **brain** and **chest**. In the default choices for each body part, a choice of these has been made; for example, soft tissue, which lowers the noise at the cost of resolution, is chosen for brains, whereas bones, which prefers resolution over noise, is chosen for bony parts. The default can also be overridden before acquiring the data.

If the choice of algorithm seems not ideal for a particular case after the reconstruction is viewed, it is easy to re-reconstruct the already acquired raw data (see the User Manual instruction), giving a new set of images from the same raw data and therefore without any need to re-sedate the animal or use additional dose. For example, this might be used for a brain scan where both the soft tissue and details of the sinuses are desired.

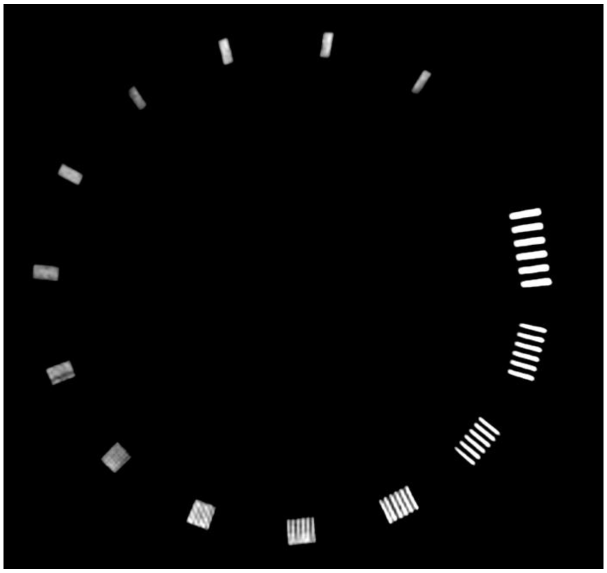

Figure 114

(4) Speed: rotation speed, image recon speed

As mentioned, the current limitation in rotation speed for CB CT comes from the detector panel which runs 60 frames per second at best. Since several hundred projections are needed, the minimal rotation time is about 10 sec. This makes anesthesia of the patient a requirement, and for thorax scanning, control of breathing is essential. Otherwise, motion artifacts will essentially destroy the image.

(5) Room size, power and shielding

CB CT scanners are very compact and fit in a small room of 6 x 10 feet. Power requirements have been shown to average 1 – 2 kW and powering from a standard wall outlet is possible. Shielding requirements are also quite modest and correspond to what is needed for conventional digital x-ray machines. Typical lead shielding is 0.5mm thick.

(6) Cost of ownership (initial price, maintenance, running costs)

Human CT scanners are built for large patient throughput, and they make money for the clinic. Veterinary CT scanners are built for low usage corresponding to the need of the surgeon. Cost of ownership in terms of capital cost, maintenance, power, cooling, space and personnel are dramatically lower in dedicated CB CT scanners. In most cases, a CB CT scanner pays for itself at about 5-6 studies per month.

(1) Image quality and artifacts
    (a) Pixel noise and contrast

CB CT is a high resolution, low dose technique. This seems like a contradiction in itself because the necessary dose scales with the 3rd power of the resolution. Applications must find the optimal compromise between noise and resolution. Typically, slice width of 0.3mm can be obtained with about

25 H.U. of pixel noise, good enough to differentiate abdominal structures. Brain scanning requires much better gray scale resolution, but here the size of the structures is also much larger. As a rule of thumb, structures require contrast of the order of ½ of the noise value in the background of the image to be visible.

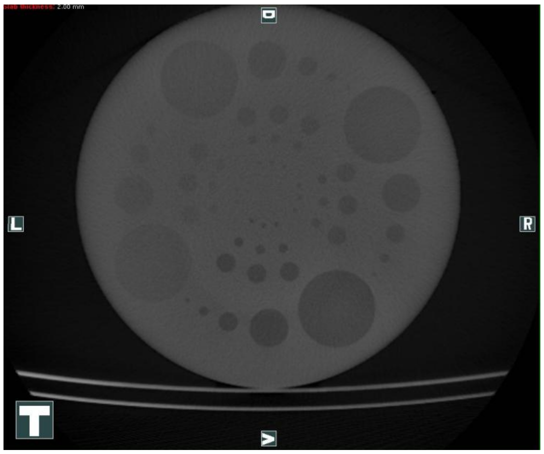

Figure 115

In general, it is necessary in almost all cases to scan with contrast injection, generating up to several hundred H.U. above water.

Figure 116

b. Artifacts:

A good understanding of image artifacts is very important when reading CT images. Experienced radiologists will be able to tell a real structure from an artifact (image errors caused by non-ideal conditions). We present a few examples of the most prevalent artifacts found in CT and especially CB CT images.

i. Cone beam artifacts

As mentioned above, the commonly used Feldkamp algorithm as well as data acquisition in stop-and-shoot mode are not sufficient for a mathematically precise reconstruction. The minimal requirements of CT are not fulfilled for voxels outside the central plane. This leads to artifacts especially if the object is inhomogeneous along the z-axis. These cone beam artifacts can be effectively removed through 2-pass corrections.

ii. Streaks

Streaks are caused by under-sampling in angular direction. This is easy to see: as the gantry moves through an angle of about 0.5 degrees, the distance between neighboring rays is d = r x $\Delta\theta$ which is easily less than the resolution size. Streaks will also come from patient motion.

Figure 117

iii. Ring artifacts

Ring artifacts have been a constant in CT images from day one. They are caused by deviations in sensitivity of detector elements. Usually, careful gain calibration will avoid ring artifacts, but in some cases software-based corrections are needed.

Figure 118

iv. Shading

CB CT with its open design cannot provide the same amount of scatter rejection as slice based CT scanners. While some of it can be corrected in software, remaining asymmetries will lead to shading artifacts.

Another source of shading comes into play when the patient is bigger than the field of measurement. If e.g. legs protrude outside the FOV, they still get in the way for some projections and not for others. This inconsistency leads to shading, and special software with estimates of what is outside the reconstruction circle must be used to correct for it.

v. Beam hardening

Beam hardening is what happens to the x-ray spectrum when the rays go through material. Especially bones with their high content of calcium will remove the low energy parts of the spectrum more effectively than water-like substances. The manufacturers correct for this by global corrections (which avoid cupping artifacts) and by 2-pass bone corrections. These corrections in CBCTare the same as in fan-beam machines.

vi. Partial volume

This artifact shows as streaks. It is caused by rays going through parts of a voxel. If there is high contrast (e.g. bone in water), the measured attenuation is somewhere between what is expected from either one, and a non-linear combination leads to inconsistencies. The only remedy is using large voxels and small ray spacing, a method which has natural limitations.

vii. Patient motion

If the patient moves during data acquisition, projections become inconsistent as they belong to slightly different objects. The result is streak artifacts and blurriness. CB CT scanners are therefore not well suited for cardiac scanning, and breathing must be suppressed during gantry rotation. The use of triggerable ventilators is recommended (see section 5).

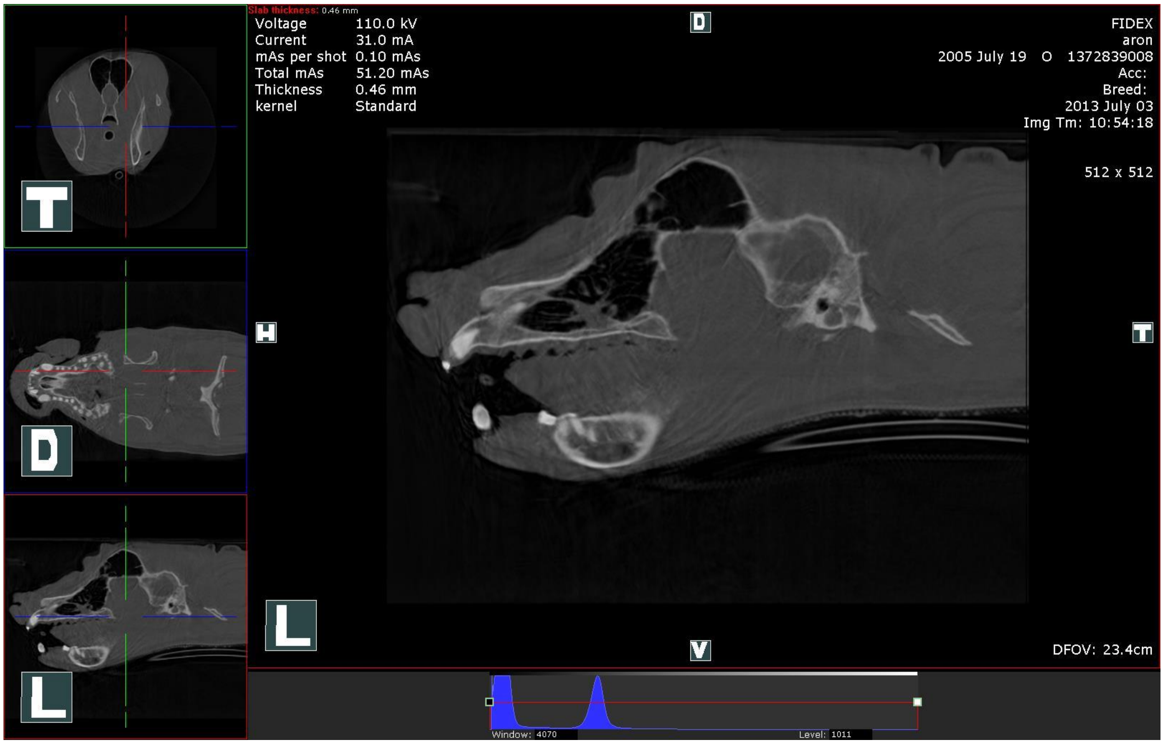

Figure 119 – motion artifacts

viii. Scanner misalignment

All CT scanners are sensitive to geometric misalignments of the scan geometry. While conventional CT scanners have tube and detector mounted on massive wheel-shaped gantries, the open design of many CB CT scanners need careful consideration of gantry flex under gravity or acceleration. Manufacturers have learned to measure the geometry precisely, so this is not an issue anymore.

ix. Metal artifacts

Metal is the enemy of CT. Metal s tend to introduce non-linearities, exaggerate inconsistencies in the data if there is only slight patient motion, and sometime they block off radiation completely. Fan-beam machines have problems scanning e.g. metallic hip replacements, and the first dental CB CT machines had a lot of trouble with gold inlays.

Figure 120

Fortunately, animals rarely contain metal implants, and the cases of bullets or BB's occasionally found in companion animals that have been shot at do not present diagnostic problems. Still, metal artifact reduction software is an active field of research, and good progress has been with iterative correction techniques.

x. Scanner malfunction

Occasionally, the collimator has been observed to malfunction by moving one of the vanes into the radiation field for some projections. This can destroy the image and the study has to be repeated.

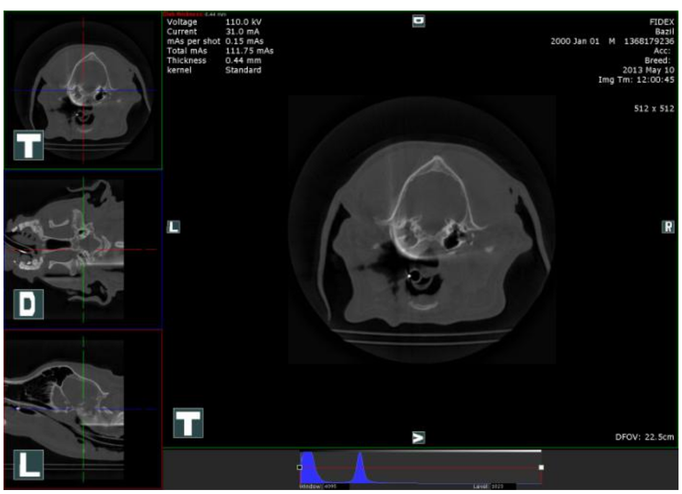

Figure 121

Future applications for Fidex

The Fidex CBCT system has been designed specifically for the veterinary market, and new applications are constantly being developed. One example is shown below: dental panoramic views. This may also be useful for the evaluation of spine scans.