Canine Noninvasive Stereotactic Frame

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Abstract

One of the most viable options for treating canine head tumors is to undergo radiation therapy. A stereotactic frame is needed to accurately position the anesthetized canine's head into the same position for each treatment. The purpose of this device is to provide a noninvasive frame which will position the canine's head while incorporating a bite block, which will keep the canine's mouth open during treatment. The device will be mounted onto a Computed Tomography (CT) and tomotherapy table and should not interfere with the radiation. In addition, the frame should be reusable and adjustable so that the canine's head can be repositioned to within 0.5° of its position during the first treatment. The device will have many adjustable parts that will allow it to change the pitch, yaw, and height to fit all sizes of canines. A model of the final design has been constructed which is fully adjustable in pitch and yaw, as well as for different sized dogs. The model revolves around the bite block, which slides up and down on two poles to adjust to different sized canines. The bite block will clamp around a custom made disposable dental mold and be rotated in two directions to change the pitch and yaw of the canine's mouth, which will in turn adjust the positioning of its head. The entire model is enclosed by a Z/N frame which provides the stereotactic coordinate system. Future work will include purchasing the correct type of carbon fiber, constructing the prototype, and testing the accuracy of the device before allowing it to be used in radiation treatment.

Problem Statement

While there are other stereotactic frames available, this device will be different because it will be noninvasive and interchangeable for many subjects. This device should be able to adjust the canine's head with a 10° range to be within 0.5° of its position during the first treatment. Since the majority of treatments will be for nasal or jaw tumors, the mouth must be kept open during the treatment to ensure that the minimal amount of healthy tissue will receive radiation. Additionally, there will be an endotracheal tube that continually provides anesthesia to the canine. A bite block that is able to clasp onto different sized dental molds of a canine's upper jaw will be attached to the central part of the design. While the dental mold will be disposable, the rest of the frame should be reusable. In addition, a strap will be placed around the mouth to keep the lower jaw from hanging freely. The material used for the frame should be lightweight and have a low atomic number to ensure that it does not interfere with the radiation. Most importantly, the device should not harm the canine.

Background

The most common treatment for cancer to date is by using radiation to kill cancerous tumors; over half of all people with cancerous tumors in the United States are treated with radiation therapy (National Cancer Institute 2008). Likewise, tumors in canines are frequently treated with radiation therapy, which involves the use of ionizing radiation to reduce tumors by killing cancerous cells (National Cancer Institute 2008). The cancerous cells die because of the damage done to their DNA upon receiving radiation. Radiation also limits the ability of cells to grow and divide, which reduces tumor growth (National Cancer Institute 2008). Radiation therapy has proven to be a very successful treatment for tumors, as is evident by its frequency of use. One of the major drawbacks of radiation therapy, despite its success and utility, is the damage done to healthy tissue surrounding the tumor in the process. Just as radiation kills cancerous cells, it is also harmful to healthy cells. The quantity and intensity of radiation that can be given to the tumor is limited severely by the amount of radiation that the surrounding healthy tissue can receive without detrimental effects. Therefore, not as much radiation can be given to the tumor as might be needed to be effective (Lester *et al.* 2001).

A different form of radiation therapy – Intensity-Modulated Radiation Therapy (IMRT) – addresses this issue. IMRT is a form of radiation therapy for cancerous tumors that allows the most intense dose of radiation to be delivered to the tumor while the sensitive healthy organs surrounding the tumor receive significantly less intense radiation (Mayo Clinic 2008). Beams of radiation are shot at the tumor in IMRT by a medical linear accelerator (Radiological Society of North America 2008) from several different angles and are controlled to give the maximal amount of radiation to the tumor, while minimizing the detrimental effects to the healthy surrounding organs (Mayo Clinic 2008). In order to avoid healthy organs, the shape of the radiation beam is changed hundreds of times throughout the treatment to bend around the healthy organs to hit the tumor with the most intense radiation (Mayo Clinic 2008).

The specific radiation treatment given to each patient is determined before the IMRT by first using a CT scan to determine the anatomical position of the tumor. Because canines cannot be expected to stay still during the CT scan, they are anesthetized throughout the procedure to ensure that they remain in the necessary position. Then, the best radiation treatment to maximize dosage to the tumor and minimize dosage to the healthy tissue is designed by a computer program based on the CT scan. Finally, the canine is placed on a tomotherapy table in order to receive the radiation treatment. Due to the complex motions required for the radiation beams, it is imperative that the canine is positioned in precisely the same way on the tomotherapy table as the canine was on the CT table.

This reproducible positioning requires some sort of patient-positioning device to use to plan treatments and ensure a reproducible position of the patient (Mayo Clinic 2008). If the patient is

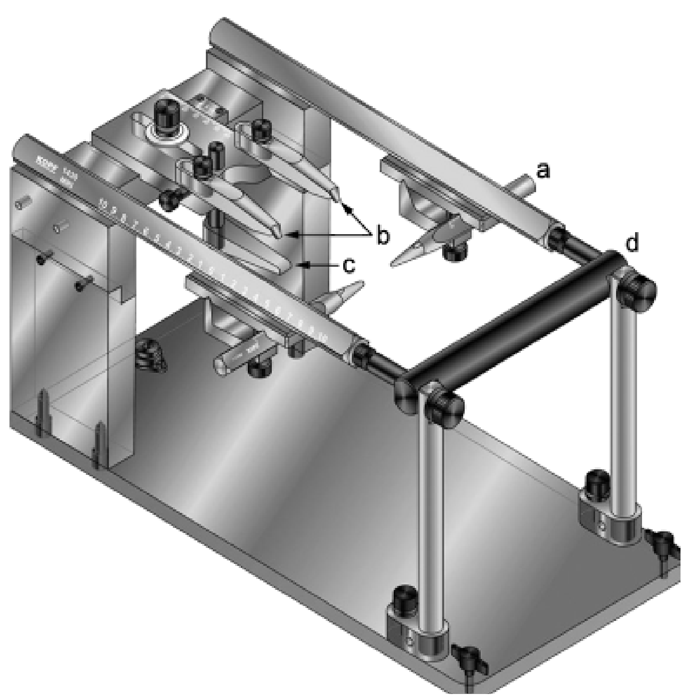

Figure 1: The Kopf stereotactic frame system shown to the right is one device that has been made to accurately and reproducibly position a dog's head during canine brain biopsy. As the picture shows, this frame works by sticking two ear bars (at position "a") into the dog's ear canal in order to ensure reproducible position. The parts at "b" and "c" are eye bars that are positioned on the lower part of the eye socket (Troxel and Vite 2008).

positioned even the slightest bit off when given the radiation, the most intense radiation may be targeted at healthy tissue, which will destroy the healthy tissue and not destroy the tumor. Destroying healthy surrounding tissue is especially problematic in IMRT done on and around the brain as the brain is the most important organ. Several different methods for reproducibly positioning the human head with a stereotactic frame for IMRT have been used successfully. However, this is not the case with canines, and the same devices for positioning the human head cannot be used to accurately and reproducibly position a dog's head due to large anatomical differences. In addition, there is more variability in the head sizes and nasal shapes in dogs than in people, which makes a universal positioning system less feasible.

Figure 2: This device, shown with a feline, is compatible with smaller animals because padding can be placed underneath the animals (Troxel and Vite 2008).

A few designs have been made and tested for accurately and reproducibly positioning a canine's head, though none have been made specifically for IMRT. Figure 1, called the Kopf Stereotactic Frame, positions the canine by having an ear bar on either side of the ears that sticks directly into both ear canals (Troxel and Vite 2008). This design is intended for CT-guided stereotactic brain biopsy, using a needle to inject contrast medium into the brain for determine accurate placement (Figure 2). A clear advantage that this frame has is its versatility: it can be used for a wide range of dogs and cats due to its adjustability (Troxel and Vite 2008). This device has been shown to be competent at reproducibly positioning the patient within about one millimeter. However, the Kopf Frame is invasive due to the needle that must be put into the animal's head to position it correctly, which is not ideal for IMRT because it is given every day for about two weeks.

Another stereotactic frame—Figure 3— was made by Nola Lester *et al.* (Lester *et al.* 2001). Like the Kopf Frame, Lester's frame was not designed for IMRT, but was intended to position the canine's head for radiosurgery. The frame in this design keeps the dog in a reproducible position by screwing into the dog's zygomatic arch with a plastic pin (Lester *et al.* 2001). This frame keeps the dog in a rigid position between the CT scan and the radiation treatment, but, like the Kopf Frame, Lester's frame is

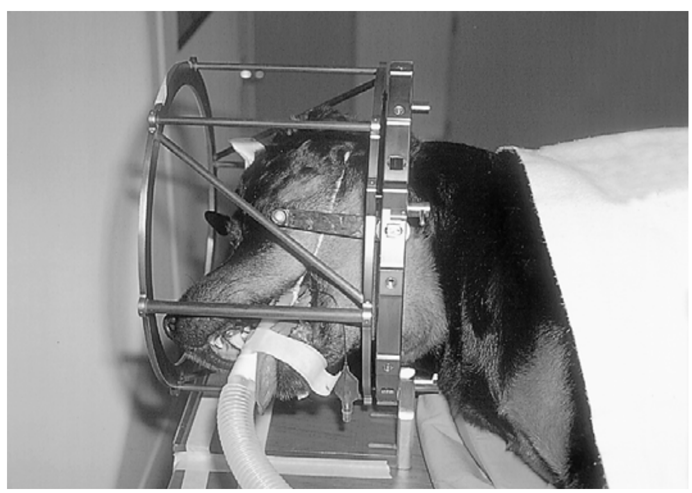

Figure 3: The dog shown above is set up in Lester's stereotactic frame. The tube going into its mouth is providing anesthesia during the surgery, and the frame is screwed into the dog's zygomatic arch with a plastic pin (Lester *et al.* 2001). This frame is compatible with large dogs, such as the one pictured, but it is incompatible with smaller dogs because it cannot screw into their zygomatic arches to keep them still.

invasive and therefore not ideal for IMRT. In addition, another problem with this frame is its lack of versatility because it is only usable for larger canines.

Design Considerations

Since most of the current stereotactic frames for canine radiation procedures are invasive, the client would like a noninvasive stereotactic frame specialized for canines during IMRT. The device must fit into both the CT and tomotherapy table, which have a diameter of 0.51 m and 0.84 m, respectively. The Z/N frame is the stereotactic component of the design which will be attached to the outside of the device to provide a coordinate system for reference. The device must incorporate a dental mold, which will be created by the Dentistry and Oral Surgery Department at the School of Veterinary Medicine at the University of Wisconsin.

Final Design

This design includes multiple adjustable and locking parts to fit the changes needed to replicate positioning for different sized dogs. The frame consists of a rotating plate for pitch adjustments connected to a collar on each side which can move up and down on two poles. These collars can then be aligned with measurement lines on the poles and locked in place using pins. On top of the frame's plate is an adjustable clamping system to hold the canine's dental mold. This clamping system is able to fit various sized dental molds and also can rotate in the plane of the rotating plate for yaw adjustments. Underneath the rotating plate is an adjustable strap that can be tightened so the dog's jaw is not freely hanging. The rotating plate and dental clamping system is locked into place using pin and socket locks. Surrounding the whole system is a Z/N frame which provides the stereotactic coordinate system for the CT and Tomotherapy machines.

The model will be constructed out of carbon fiber due to its low atomic number, strength and durability. The carbon fiber should be thick enough to support at least 13.6 kg, but should not be too cumbersome. To provide thickness without using excessive amounts of carbon fiber, balsa wood can be sandwiched in between two carbon fiber sheets and attached with adhesive and plastic screws. The balsa wood would also reduce the overall weight and make the design more cost efficient. Although carbon fiber can be molded to fit custom shapes, all the forms needed for this model is commercially available, such as rectangular sheets, circular disks and solid and hollow cylindrical rods.

Bite Block

Figure 4: Front view of the model with bite block and adjustable system in the foreground. It includes vertically moving collars, rotating plate for pitch, and rotating disk for yaw adjustments.

The bite block (Figure 4) is the adjustable system that holds the canine's jaw in place. The system is able to move vertically to adjust for different sized canines and also in pitch and yaw to correct for any positioning error (within 0.5^{o}) that occur from transferring the canine from the CT to Tomotherapy machine.

The bite block's height is able to be adjusted on the rods by sliding the collars up and down the rods and locking into place with pins. Measurement lines will be on the poles so the measurements can be recorded manually for each procedure. To adjust in pitch, the circular disk system will be used. There are two disks on each side—one, which is slightly larger than the other, is attached to the collar and the second is attached to the plate. The plate will be attached to the circular disks which can rotate about an axis and be locked into place with pins. Measurement lines similar to a protractor will be drawn on the outside disk to allow the user to record the pitch position by aligning the smaller and larger disks to the correct measurement. To allow for more accurate positioning, the pin holes can be offset to provide smaller increments. The yaw position can be adjusted by rotating the circular piece in the middle of the plate. The rectangular extensions attached to the circular piece are used to adjust and align in yaw. A measurement system similar to the one used for pitch adjustments will be used for reproducibility.

Figure 5: Canine dental mold made manually with no tray. Therefore, it does not have the flat surfaces necessary.

The canine's jaw is fixed into the system with the dental mold (Figure 5). The dental mold is made by mixing medical red and white putty, which is placed on a tray and then molded to the canine's teeth. The putty hardens within minutes and will hold its shape for up to two weeks. The current dental mold tray incorporated is not reusable, but a reusable one would be ideal. The dental mold will be secured into the rotating circular piece in the center of the plate using movable supports. The canine's upper jaw is locked into the dental mold, but the lower jaw is not. In order to provide support and enhance reproducibility, an adjustable strap made of nylon webbing with a carbon fiber buckle is used to secure the canine's lower jaw under the bite block.

Z/N Frame

The Z/N frame (Figure 6) surrounds the design to provide the stereotactic coordinate system. The frame is attached to the device on the top and the two sides parallel to the canine's head. It is composed of hollow carbon fiber rods that have a tube of a radioactive material— gadolinium— inside. The gadolinium is detected by the computer to provide reference points because each image contains three points from each rung of the Z/N frame. The rods containing gadolinium can be removed and replaced as needed.

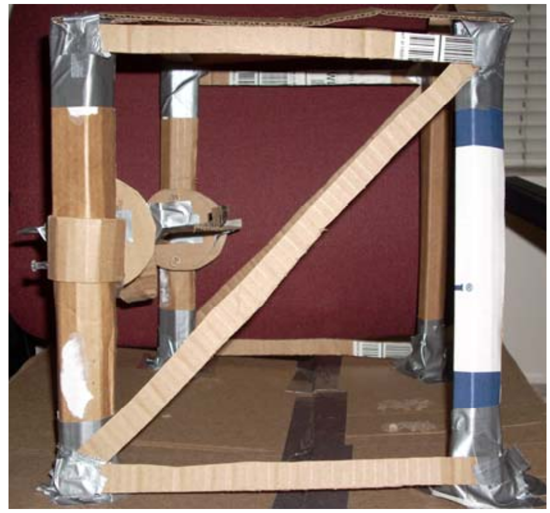

Figure 6: Side view of the model displaying the Z/N frame. The 'Z' in the foreground lines up with the one in the background. The gadolinium rods snap into each leg of the 'Z.'

Future Works

A working model illustrates the feasibility of the design. Based on knowledge gained from specialists, carbon fiber construction techniques have been determined. Future work includes obtaining carbon fiber to begin fabrication of the prototype. After all necessary components have been completed and the prototype has been assembled, the device must be tested with an anesthetized canine to confirm that it provides the accuracy and adjustability needed for radiation treatment. Once testing is complete, the prototype needs to be updated and finalized to be used in future radiation therapy treatments.

Another aspect that needs to be developed is a more consistent and accurate method to make canine dental molds. Currently, a sheet of rigid foam is heated and manually formed into a tray. Because each tray is individually made, there is no consistency between the shapes of the dental molds. In order to ensure that the molds fit snuggly in the bite block, they need to be created with a similar shape. This could be done by developing reusable trays that provide a constant shape for all of the dental molds. In addition, different sized trays can be made to compensate for the size variation of canine jaws. A final future consideration is to make the design compatible with biopsy equipment. The biopsy equipment would be able to attach to the frame to make a 180° track around the canine's head.

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Appendix A: Product Design Specification

Project Design Specification—Stereotactic Frame

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Function:

The purpose of the noninvasive stereotactic frame is to hold the canine's head in a fixed position for repeated dosage of intensity modulated radiation therapy (IMRT). The positioning for each dog should be reproducible for each treatment. The device should be reusable and adjustable for different species of dogs with varying body size. The materials used should be able to withstand and not interfere with the radiation therapy procedures.

Client Requirements:

- The frame should be reusable for all dogs
- The device should be noninvasive
- Adjustable parts that allow the canine's head to be moved over a 10° range in pitch and yaw
- Reproducible positioning for each dog for every treatment
- The device should not interfere with the radiation treatment
- The device should be cost efficient

Design Requirements:

1) Physical and Operational Characteristics
    a) *Performance requirements* – The device should hold the subjects in a fixed position during IMRT treatment for up to ten uses a day.
    b) *Safety* – The device should not hurt the canine during IMRT. Also, there should be no interactions between the radiation and the prototype's material.
    c) *Accuracy and Reliability* – The device should be able to repeatedly position the canine's head to within 0.5° in pitch and yaw for every treatment.
    d) *Life in Service* – The device will be used for several years, with multiple uses each day.
    e) *Shelf Life* – The device should be able to withstand everyday laboratory and radiation therapy environment.
    f) *Operating Environment* – The device will be sterilized after each use and it should be able to withstand the IMRT without degrading or interfering with the radiation treatment.
    g) *Ergonomics* – The device should not interfere with regular IMRT procedures.
    h) *Size* – The device should be able to fit inside the tomotherapy machine, which has a diameter of 83.8 cm
    i) *Weight* – The device should be as lightweight as possible.
    j) *Materials* – The device should be constructed using cost-efficient material. The material should have a low atomic number, preferably carbon fiber. The materials should be able to withstand IMRT and follow animal care policies.
    k) *Aesthetics* – The device should not affect the radiation procedure.
2) Production Characteristics

a) *Quantity* – The goal is to produce two devices, one for the CT machine and one for the tomotherapy machine. However, it should be designed with the intent of mass production in the future.
b) *Target Product Cost* – The device should cost under $1,500

3) Miscellaneous
    a) *Standards and Specifications* – The device should not harm the canine during the IMRT. It should also be animal friendly.
    b) *Customer* – This device will be used by the veterinary community when treating canines, and possibly felines as well, who have tumors in their head
    c) *Patient-related concerns* – The device should be non-invasive and should not harm the canine's well-being.
    d) *Competition* – Other stereotactic frames currently exist. However, they are used with smaller animals and are invasive and nonreusable.