

APPLICATION OF SFF TO PREOPERATIVE PLANNING AND SURGICAL REHEARSAL FOR TREATMENT OF LIMB DEFORMITIES IN DOGS.

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Abstract

This report describes SFF-aided assessment and preoperative planning for treatment of bilateral multifocal pelvic limb deformities in a one-year old German Shepherd dog. CT scans were converted to solid models and stereolithography patterns were prototyped. RTV silicone molds were constructed and three sets of polyurethane patterns were cast for pre-surgical rehearsal. The paper compares traditional osteotomy planning procedures, planning via virtual prototypes, and planning with full-scale physical prototypes.

Introduction

Bone deformities are relatively common in both humans and animals. Most deformities are developmental and are treated early, in skeletally immature patients. Adults also have deformities that may result from metabolic diseases, malunions, or untreated developmental deformities. Corrective osteotomies are generally performed in one or more locations to treat these deformities. A precise and accurate preoperative planning is critical to the success of these procedures and is difficult to achieve using radiography and 2-dimensional computed tomography (CT).

A one-year-old female German Shepherd dog was referred from Charleston, SC to the orthopedic service of the College of Veterinary Medicine at North Carolina State University (NCSU) in November 2001 for evaluation and treatment of multifocal deformities of the pelvic limbs. The dog had angular and rotational deformities affecting femora and tibiae. Due to the unusual nature of these deformities and their geometric complexity, the information collected from the orthopedic examination and from radiographs of the pelvic limbs was considered to be insufficient for preoperative planning. In February 2002, the orthopedic clinician (DJM) learned about the medical modeling capability available in the Industrial Engineering Department at NCSU. Biomodeling was first fully developed during a European project called PHIDIAS [1-3]. Biomodels have been used for over a decade to diagnose, plan and rehearse medical procedures on human patients with great success [4-7]. Biomodels have been used in the veterinary medicine to aid in reconstruction of skull deformities but, to our knowledge, biomodels have not been used to assess deformed limbs and plan and rehearse corrective osteotomies. A CT scan of the pelvis and pelvic limbs was performed upon return of the dog to NCSU, and three full-scale biomodels were prepared.

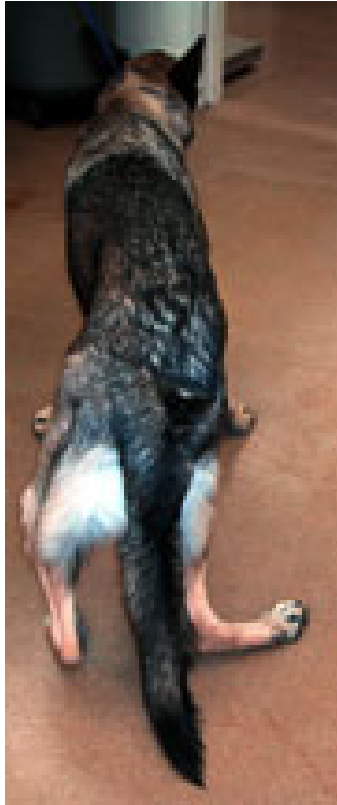


Figure 1 - Rear View of German Shepherd Showing Bone Deformities

Materials and Methods

A CT-scan was acquired at the radiology department using a General Electric Computed Tomography scanner. The scan was performed at 0 gantry tilt, and helical scanning was used for faster and more accurate images. The helical scan was reconstructed into 1 mm slices with a resolution 512x512 and a total of 566 images were produced covering the dog from pelvis to extremities. Because of the unusual scanning protocol and the large size of the region scanned, three trials and GE technical support were needed to acquire optimal images. The reconstructed CT-data was transferred to a CD and loaded into the Mimics software (Materialise, Belgium) [8] that is used at the Rapid Prototyping Laboratory at the Industrial Engineering Department at NCSU. The final scan was performed in two separate sections with a waiting time in between. Unfortunately, the patient moved slightly during the wait, thus causing a misalignment of the lower limbs in the CT data. In Mimics, the images were edited one by one to provide a solid model without interior cavities. Through region growing, a 3 dimensional model of the dog's hindquarters was made.

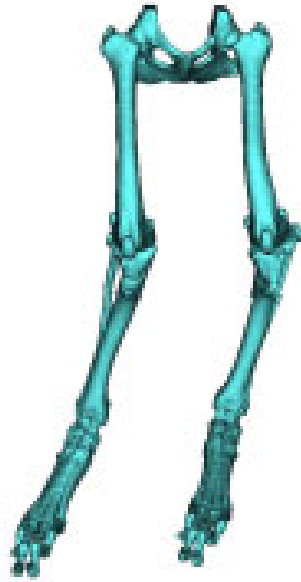


Figure 2 - 3D-model dog's pelvic limbs created using Mimics

To fabricate the model, an SLA-190 from 3-D Systems was used with a build envelope of 190 x 190 x 250 mm. Due to the shift in the tibial portion of the computer model, the computer model was separated into two sections that were exported to the STL file format. To fit the model onto the relatively small build platform, the STL files were imported into Geomagic Studios by Raindrop Geomagic [9] and divided into a total of 11 sections. Three build platforms were prepared using the Lightyear software from 3D Systems, and the build style was set to QuickCast to save time, resin and laser hours. Three sets of solid models were requested by the surgeon to plan and rehearse the surgical procedure. One model was to be used to plan the complicated surgery. The second model was to be kept for reference in the operating room. The third model was created just in case an extra model was needed during the pre-surgical planning session. In order to produce the three models, one-piece RTV silicon rubber molds were produced using the QuickCast patterns. A total of seven silicon rubber molds were needed to produce the different bones. The three sets of bones were produced, assembled, finished and painted to give a natural look (Figure 3).

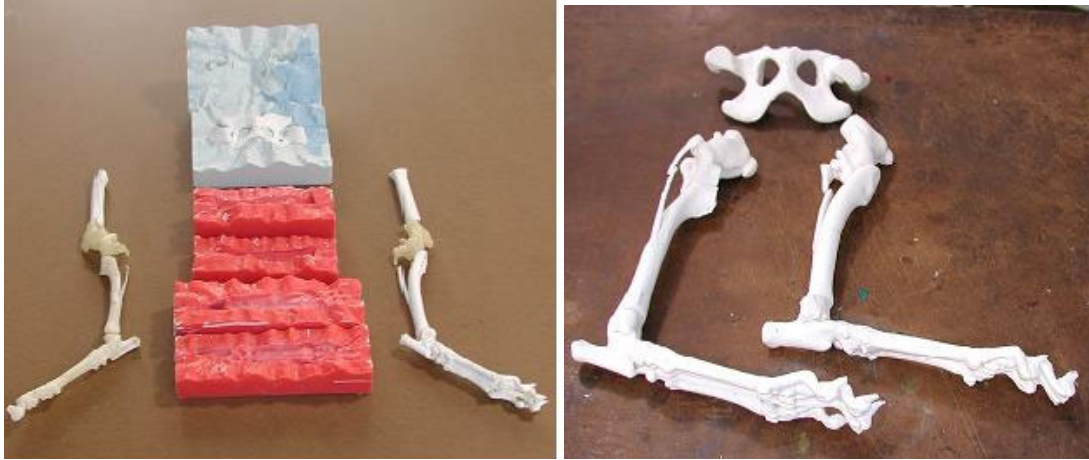


Figure 3 - Silicon molds and polyurethane parts of dog model

The right pelvic limb was operated on first. Based on the radiographs and the images from the CT-scan, the surgeon had anticipated performing one femoral and two tibial osteotomies to correct the deformities of the right pelvic limb. When the models were presented to him, it was concluded that only the tibial osteotomies would be needed. The pre-surgical rehearsal was performed the day before surgery. The original plan was to perform an opening wedge osteotomy and to use a hinged circular external fixator to correct the proximal end of the tibia. A closing wedge osteotomy with a fixating plate was to be used to correct the distal end of the tibia. After working with the model for some time while designing and assembling the external ring fixator, the surgeon decided to correct the deformity by only performing one osteotomy using the external ring fixator at the proximal end of the tibia. Using the model, it was concluded that a medial angular correction of 22 degrees was needed along with a medial rotational correction of 11 degrees. Following assembly of the ring fixator, the entire surgical procedure was performed using one of the models, and notes were taken to assist the actual surgery the following day.

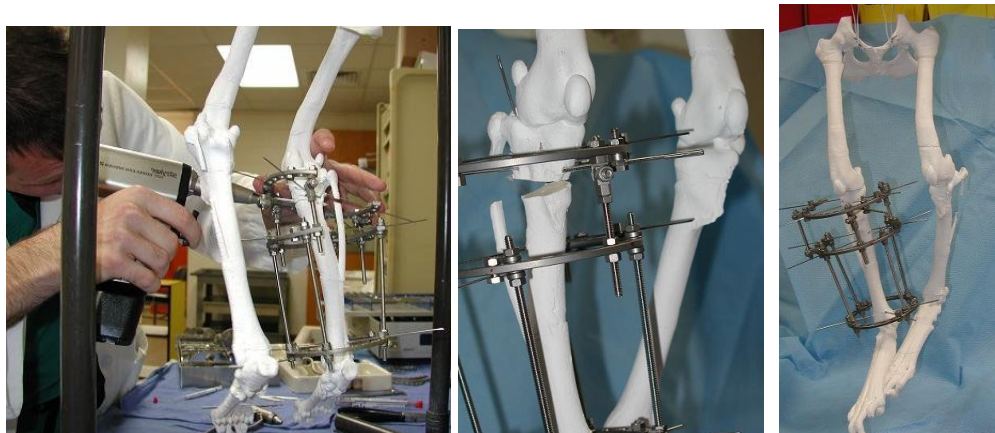


Figure 4 - Pre-surgical rehearsal on biomodel

The first step of the pre-surgical procedure was to attach the frame's three rings to the tibia using wires that were drilled through the bone and then attached to the frame with wire fixation

bolts. The wires were later tensioned to increase their stiffness. Half-pins were added to increase the stability of the fixator. The half-pins were threaded into the bone and bolted on the rings. After the external fixator was securely attached to the tibia, the bone was cut between the two upper rings. The distal portion of the tibia was rotated medially 11 degrees. The frame was then adjusted angularly 22 degrees to check if desired correction had been achieved. The objective of the two corrective adjustments (22 degree wedge and 11 degree rotation) was to achieve proper alignment between the dog's hip, knee, and foot. After concluding that the practiced procedure did, in fact, produce the desired result, a second frame was assembled and prepared for surgery the following day.

The next day, the German Shepherd was prepared for surgery, and the surgical team was briefed about the planned procedure using the biomodel. Two models were used in surgery as references - the one with the frame and one that was untouched. The surgeon performed the surgery following the exact procedure rehearsed the previous day and frequently consulted the models for additional information.

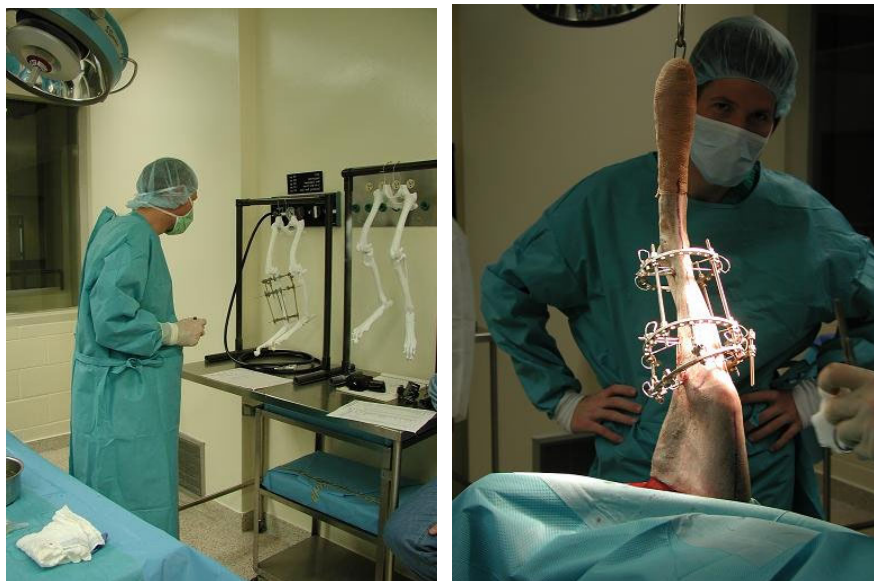


Figure 5 – Biomodels in the OR (L) and Attached Ring Fixator (R)

Despite the fact that a 22-degree wedge was ultimately needed to achieve the desired result, it was not possible to produce this extreme correction entirely during the surgery. This is due to the fact that muscles, ligaments, and tendons can only be stretched so far before they will tear. The external ring fixator is hinged on one side and has an adjustment screw on the other side that allows the surgeon to gradually increase the wedge angle over a period of time (i.e. a progressive osteotomy). In this case, an adjustment of 1-2 degrees per day was made until the final 22-degree angle was achieved.

After the final adjustment was completed, the dog was sent home with the external fixator in place to allow the bone to heal back together. After two months, the dog returned to the Veterinary School to have the frame removed. The entire procedure was then repeated to straighten the dog's left rear leg. A new pre-surgical rehearsal was conducted using the second biomodel. The deformity of the left tibia was very similar to the right, and the same procedure

was planned and practiced. The most significant difference in the two surgeries was that the left femur (thigh bone) had a deformity that required a closing wedge osteotomy with a fixating plate. After the rehearsal, it was concluded that the left tibia also needed a 22-degree angular correction but that no rotational correction was necessary. The actual surgery was performed the following day, and the biomodels were once again used as references during surgery. Measurements were taken directly on the model to determine where to make the incisions and where to locate the osteotomy sites. The surgery followed the exact same procedure developed during the rehearsal the previous day. The progressive angular correction is currently taking place, and the German Sheppard will wear the external fixator until the end of August 2002.

Results

The overall outcome of the project was a success, and many lessons were learned. The decision to use QuickCast models to create the silicon molds turned out to be very helpful, since the SLA-190 is a very slow machine that does not have a recoating blade. Since this project was initially started, the university has acquired a Z-Corp machine whose accuracy is perfectly acceptable for the types of pre-surgical planning models used in this project. The making of the silicon rubber molds was a very time consuming and expensive process. In some cases, it was quite difficult to properly vent the molds, and the resulting polyurethane castings had trapped air pockets. While the flexibility of the rubber molds made it possible to demold complex shapes with small to moderate undercuts, demolding was still a very difficult proposition. Due to the need to produce the molds very quickly, one-piece cut molds were produced for all parts instead of two-piece molds that had built-up parting lines. The process of cutting the molds with highly complex parting lines was a significant challenge. Final assembly of the separately cast bones was more difficult than it needed to be due to the fact that interlocking features were not added to the parts in the CAD system. The different parts were glued together using fast setting two-component epoxy glue with a cure time of 2 minutes. Keeping the bones aligned, and holding them in the right location for over two minutes while the glue cured was a challenge. In hind sight, it was decided that building parts in the QuickCast build style and then filling them with polyurethane would be much faster and less expensive than building RTV molds. Furthermore, a positively locating joint between each bone will be designed to facilitate the assembly of future models.

The results of the pre-surgical rehearsal and the surgical procedures were a success as well. Post-operative radiographs from both the first and the second surgery showed excellent limb alignment. The final surgical result will not be available until the end of August 2002 when the second external fixator will be removed. However the surgeon is confident that the result will be better than first anticipated and the dog will most likely be able to ambulate normally without any noticeable deformities. The dog ambulated with difficulty before surgery and was improved after the first limb was operated. It is anticipated that the second surgery will fully restore mobility of the pelvic limb.

Discussion

Using biomodels to plan and rehearse complex osteotomies of severely deformed bones has obvious benefits. The models give the surgeon a chance to determine if the planned procedure will succeed or if it is better left alone. Further, the ability to fully plan and rehearse a surgical

procedure in advance saves valuable time in the operating room, and substantial cost savings can be experienced. The time a patient is under anesthesia is critical and should be minimized. Routine cases would probably not benefit as much from the use of biomodels, but the more complex and unusual cases definitely will. Even cases earlier considered impossible can now be performed with help of new tools made available to the surgeons. It could be argued whether or not it is economically and politically correct to spend money on biomodels to treat animals with severe deformities. It is noted, however, that many pet owners are very committed to their animals and would do almost anything to help them. The money spent on the biomodels will, in most cases, save enough time in the surgery room to cover the cost of the models. Further complications can also be avoided since the surgeon has more information to base his or her decision on, and the risk for making a mistake is therefore reduced. According to the surgeons involved with this project, they were much more confident when they started the surgery, since they had already done the entire procedure and had a very good idea of what to expect. A biomodel takes out most of the guesswork that a surgeon usually has to struggle with on a daily basis.

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