Cleft lip and palate is the most common birth defect in the United States affecting one of every 594 births (Centers for Disease Control, 2006). A cleft palate is a condition in which the palate (i.e. roof of mouth) does not grow together during gestation. As a result, a hole is created in the palate that may extend into the nasal cavity. Problems related to feeding, maxillary facial growth, dentition, hearing, and speech are just a few of the obstacles these children and their families will encounter throughout the child’s life. A child born with a cleft palate may undergo multiple surgeries to restore anatomy and regain muscle function. The goal of surgery (i.e. primary palatoplasty) is to close the cleft and restore normal sounding speech. In individuals with a cleft palate, the major muscle responsible for normal sounding speech, levator veli palatini (levator), has an abnormal and unfavorable position. Before surgery, the muscle is anchored to the posterior aspect of the hard palate. During surgery, this muscle must be dissected off the hard palate and repositioned to form a sling with the opposing levator bundle. This muscle arrangement is critical in order for the child to develop normal sounding speech. However, it is estimated that 20-30% of individuals with a cleft palate will have nasal sounding speech even after primary surgery (McWilliams, 1990). This may be due to inaccurate repositioning of the levator muscle during surgery. A major drawback to current surgical practices is that there is limited presurgical planning. Most methods include inspection of 2D data, such as lateral view x-ray. However, the levator muscle cannot be viewed in lateral view x-ray due to the image contrast and image plane. In addition, 2D data information tends to simplify the complexity and variability of the internal anatomy. Without inspecting the levator muscle before and after surgery, only assumptions can be derived. For example, it is not known for certain whether the levator muscle was relocated correctly and with adequate mass and length. Often, it is not until three to four years later when the child sounds hypernasal that a subsequent surgery reveals that the muscle was not initially positioned correctly. An overall lack of research in pre and postsurgical assessment limits quantitative data regarding normal verses abnormal levator muscle length, thickness, and angle of insertion.

Magnetic resonance imaging (MRI) is the only imaging medium that allows for visualization of the entire levator muscle. Recent work in MRI has been conducted to investigate the specifics of the levator muscle. Kuehn et al. (2001) imaged two children who exhibited hypernasal speech to demonstrate the effectiveness of using this imaging modality to diagnose an occult submucous cleft palate and to direct behavioral and surgical management. Ettema et al. (2002) reported the first quantitative measures of the levator muscle during rest and speech production. Kuehn et al. (2004) imaged the levator muscle before and after primary palatoplasty. MR images were obtained between 5 days and 2 months prior to surgery and 2 to 15 months after surgery. A 1.5 Tesla system was used to obtain sagittal and coronal oblique section planes for all subjects. The study provided both quantitative and qualitative detail of the levator muscle in one infant with normal velopharyngeal anatomy and seven infants with cleft palate. Quantitative information focused mainly on the angle of the sectioned plane,
which was indicative of the steepness of the muscle as it diverges toward the insertion. Qualitative information included levator midline bulk postoperatively, muscle continuity following surgery, orientation and direction of the levator fibers before and after surgery, and angle of insertion into the palate (i.e., steepness of the fibers). Overall, it was found that the course of the muscle following surgery might be drastically changed making the muscle fibers steeper. This is advantageous in providing proper leverage for the velum during elevation. The authors also mention that MRI could be used as a prognostic indicator prior to surgery.

Research Objectives
By combining MRI and 3D computer modeling, the levator muscle can be imaged, studied, and analyzed in three dimensions of space. No studies have combined MRI and computer imaging technology to study the levator muscle in infants before and after primary palatoplasty. Our research is designed to prove a concept through a translational research approach. It combines basic and applied research to create a patient specific 3D computer model using MRI for pre and postsurgical analyses. The purpose of this project is to use MRI and advanced computer technology to measure the levator muscle in infants born with cleft lip and palate before and after primary palatoplasty. The clinical goals are to demonstrate the use of MRI and 3D computer technology for the purposes of presurgical planning, assessment of levator muscle morphology before and after surgery, and postsurgical assessments of the levator muscle. It is anticipated that this may improve patient care through presurgical planning, patient specific diagnosing and treatment, and may reducing human error during surgery.

Methods
Collaboration among Carle Foundation Hospital, the Department of Speech and Hearing Science, Bioengineering Department, and Beckman Institute for Advanced Technology at the University of Illinois in Champaign-Urbana has enabled innovative research that serves to improve the diagnosis and surgical treatment for children born with a cleft palate. Using Carle Foundation Hospital’s new 3T MRI scanner, infants are being scanned two months before surgery (approximately 8 months of age) and 5 months following surgery (approximately 15 months of age). The MR images are imported into a 3D software system (Amira) at the Visualization Media and Imaging Laboratory at the Beckman Institute at the University of Illinois. Using Amira software system, the structures of interest in the MR images are identified and segmented away from surrounding structures. The areas of interest include the levator muscle, skull, tongue, velum, and hard palate. The segmented structures then are combined to construct a 3D volume. The 3D structures then are imported into a high-powered 3D software system called Autodesk Maya 7.0 where the structures are easily manipulated and controlled by the surgeon. The 3D computer model can be manipulated and rotated in all directions. Superficial structures (e.g. skin and skull) can be made transparent to display the internal anatomy (e.g. levator muscle) in situ. This gives the surgeon great flexibility in viewing the internal anatomy before the surgery is performed. Presurgical planning was conducted on the first 3D computer model. A short animation was created to display the proposed surgical repositioning. A second model is then created from the follow-up MRI scan (i.e.
post-surgical MRI scans). The 3D computer model created is used to assess the accuracy of the placement of the repositioned muscle bundles. Using the model, we also can determine whether the presurgical model was beneficial. Ideally, there will be little difference between the presurgical model that was used for surgical planning and the postsurgical model.

This project also allows us to measure and evaluate the levator muscle following surgery. Using measurement tools in the Amira software, the levator muscle can be measured in width, length, distance between both origins, and the angle with which it diverges downward from the base of the skull. From these results we will be able to compare the levator muscle in individuals born with a cleft palate to those in individuals born with an anatomically normal levator muscle. Such knowledge will help us better understand the functional significance of an abnormal levator muscle. It will also help us to identify what constitutes “normal” anatomy. It is unclear, for example, what amount of variability in the angle of origin, length of the levator muscle, and distance between origins is acceptable for adequate levator muscle function. These are assumptions that imaging, particularly magnetic resonance imaging (MRI), can help to verify.

**Scientific Findings**

Using MRI and 3D computer technology, the levator muscle could be imaged and measured before and after primary palatoplasty. MRI continues to prove to be a viable imaging modality for studying soft tissue structures such as the levator muscle. The combination of 3D computer technology enables the research team and surgeon to study the internal anatomy in an entirely new way. Soft and hard tissue structures can be created into an accurate and realistic computer reconstruction that allows the surgeon to manipulate the structures before entering the operating room and study the anatomy as it exists in three dimensions.

**Conclusion**

This research is in the early stages. One infant born with a unilateral cleft lip and palate and one infant with bilateral cleft lip and palate have participated in this study. We are currently examining control subjects (aged-matched infants without a cleft palate). We have found that by using MRI and 3D computer technology, the levator muscle could be imaged and measured before and after primary palatoplasty. In addition, an accurate and realistic computer reconstruction of levator muscle and the morphologic changes during surgery could be obtained.

The clinical applications of this project are primarily for patient specific imaging and modeling for presurgical planning and assessment postsurgically. Overall, it is anticipated that a 3D model based on the patient’s MRI data will be found to be an efficient and effective means for conducting assessment and surgical and behavioral treatment thus possibly improving the treatment outcome. This research is a step closer to providing significant advances in the clinical realm such as reducing human error during surgery, presurgical planning, as well as patient specific modeling, diagnosing, and treatment. Surgical planning, virtual surgery, and computer assisted surgery are only a few areas that are being explored in other areas of medical sciences and will likely be a possibility of surgical intervention for individuals affected by a cleft palate. This
analytical tool also will be beneficial to educators training future surgeons and speech pathologists providing a visual method of examining the critical levator muscle sling.

**References**


