motor-driven actuators was constructed and was analyzed with a 6 DOF reference sensor in respect to overall actuation force and accuracy of reduction in a simulated fracture situation (Fig. 1).

Results

The speed of the actuators was found to be 2.5 mm per second at maximum. The speed decreases slightly to 2 mm per second with 50 N applied load. The direction of the applied load did not show a significant effect on the actuation speed. Cycling of different positions and power-loss of the actuator did not show an effect on accuracy. The maximum force obtainable varied with the geometry of the fixator; yet the typical maximum force for distraction was approximately 300 N. In variation to the clinical routine photographs instead of radiographs were taken frontal, lateral and from on top. The geometrical situation of the simulated fracture and the fixator was determined and processed with a control software. The robotic fixator performed the fracture reduction with a typical error of less than 1° in rotation and 1 mm in translation respectively.

Conclusions

Based on the manual hexapod fixator an "intelligent" fixator system has been developed. Effectively, it is a bone mounted robot system for fracture control. The robotic fixator ideally can be applied for outpatient treatment with distraction osteogenesis. The planned and stored motion path is followed precisely by the robotic system and the frequency of actuation can be adapted to a biological optimum thus promising improved outcome of the treatment. The system already comprises a Bluetooth transceiver for wireless communications. Telemedical checkups and adjustments of the motion path can be accomplished by using the internet capabilities of a Bluetooth enabled mobile phone. The robotic hexapod external fixator allows movements and force measurements in six degrees of freedom. This device will ultimately allow control of the healing process by adjusting the fixator's movement to the individual bone regeneration speed of the patient.

3D/3D Ultrasound registration for panoramic volume reconstruction

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Keywords Ultrasound registration · Panoramic volume · Minimally invasive surgery

Purpose

In computer assisted orthopaedic surgery (CAOS), the motion of bones is generally tracked using a three-dimensional position measurement system. This is typically carried out by invasively attaching a marker to the bone. This is performed by inserting pins or screws, creating holes and causing trauma to the tissue and structure. This may increase the risk of bone fracture, infection and cause extra pain owing to extra inscisions. The development of 3D ultrasound (US) offers interesting prospects for surgical navigation. Indeed, this non-invasive data and real-time imaging technology could reduce the invasiveness of CAOS by replacing the optical trackers which are currently used. This implies the development of a method for rigid registration in order to track a bony structure. This method has to be at the same time robust and real-time. However, due to speckle, shadowing effects and the poor quality of US images, the registration of this imaging modality is a challenging process. The approach we develop consists in registering a reference 3D US volume to real time 4D US orthogonal slices. Since little information is present in these 4D images and to maximize their overlap to the reference volume, an initial stage consists in building a panoramic reference volume by registering overlapping 3D US volumes. This paper describes this initial stage.

Materials and methods

Ultrasound data were obtained with a General Electric Voluson 730 Pro, equipped with a RSP 6-16 probe. Ultrasound volumes ($152 \times 122 \times 199$ voxels, voxel size is 0.25 mm) were acquired on the scapula of a cadaver. The particularity of our registration method is to combine the information given by the intensities contained in the image and the information given by a synthetic image based on a coarse segmentation of our images. To register the images, a voxel-based registration method is used with a Powell-Brent optimization process.

The first step of the registration algorithm is to produce a coarse segmentation of the bone interface. The method for extracting points on the interface is based on the physics of ultrasound waves. The physics of ultrasound imaging indicates that the acoustic waves in a homogeneous environment decrease according to an exponential function. To extract the bone interfaces in the images, we correlate ultrasound profiles of ultrasonic beams with an exponentially decreasing function modelling the absorption of the acoustic wave into the (cortical) bone. The correlation for local maxima of each ultrasound scan line is calculated and when this correlation is higher than 90%, a bone interface is considered to exist. The detection of the interface is not perfect and few steps are added to smooth and clean up the surface. The result of this segmentation can be used to define different regions in the image: regions corresponding to the bone interface, regions behind the interface, regions ahead of interface and regions with no specific information. Starting from these different regions, a distance to the interface has been added which enables the building of a synthetic image containing this information. This synthetic image is constructed as follows: the bone interface is modelized by a Gaussian, for the regions located in front and behind the interface a linear model is used. The linear model represents the distance to the interface. The others regions are not considered.

The similarity measure is modified to integrate the information containing in the synthetic images. A multiplicative factor is calculated on the synthetic images which penalizes the similarity measure calculated on the raw image. This factor (a kind of normalized sum of the square differences) is calculated pixel-to-pixel on the synthetic images. To evaluate our registration algorithm with a gold standard, we made a cadaver test. The gold standard reference transformation is given by an optical tracker that is pinned rigidly into the bone. 9 ultrasound volumes were collected. In our experiments, we calculated 156 registrations (the overlap between volumes being about 50%). To compare the transformation given by our algorithm to the reference transformation, we calculated the distance of 9 points of the volumes (8 vertices, center).

Results

It is generally very difficult to determine visually if a registration is correct or not. To determine automatically the success of our method, we used the Otsu's thresholding method on the average error of each registration. The threshold given by this method is 2.39 mm. The results are shown in Table 1.

Conclusion

This evaluation of the method shows that the rigid registration of 3D/3D US data works in approximately 80% of the cases with an average

Table 1 Registration results

	Success	Failure
Registration	80.12%	19.88%
Min	0.67	2.83
Ave	1.89	3.76
Max	2.82	4.94
Std	0.23	0.51

error of 1.89 mm. The next step of our work is to extend the algorithm to tracking.

A comparison of conventional guidewire alignment jigs with imageless computer navigation in hip resurfacing

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Keywords Hip resurfacing · Imageless computer navigation · Conventional alignment jigs · Femoral guidewire

Purpose

The purpose of the current investigation was to determine the accuracy and precision in placement of the initial femoral guidewire with conventional alignment jigs in hip resurfacing and to compare results to imageless computer navigation.

Methods

Five commercially available jigs were obtained [2 lateral pin (LP); 2 neck centering (NC); 1 head planing (HP)]. Four surgeons used each jig 3 times in a randomized fashion to drill a guidewire in 10 degrees of relative valgus alignment and neutral version in individual synthetic femurs. Each surgeon used imageless navigation to drill three consecutive guidewires following jig use. Utilizing human cadaveric femora, a single surgeon used each jig 3 times in a randomized fashion to align the initial guidewire in 10 degrees of relative valgus alignment and neutral version in each of 10 dried femora. Guidewire alignment for each jig use was verified by navigation. Following jig use, a single navigated guidewire was inserted. Anteroposterior and lateral radiographs of the synthetic and human femurs were taken to assess guidewire inclination and version.

Results

Using synthetic femora, the only significant difference in coronal alignment accuracy occurred between the two Neck Centering jigs ($p = 0.028$) (Table 1). With respect to version accuracy, there was a significant difference between the two Lateral Pin jigs ($p = 0.049$). In addition, jig LP1 produced a mean version error of 1.8 degrees retroversion (SD 5.9) while the other jigs and Navigation erred in anteversion (0.3–4.9 degrees, SD 3.8–6.5). Compared to Navigation (range −2–2 degrees coronal alignment error, −11–5 degrees version error), the range of error for the jigs was up to 8 times greater in coronal alignment (Fig. 1) but similar in version (Fig. 2). There were significant differences in coronal alignment error obtained between surgeons ($p < 0.011$) while there was no difference between surgeons in version error ($p > 0.156$). With regard to coronal guidewire alignment precision, Navigation (1.3 degrees, SD 0.5) was more precise than all alignment jigs (1.3–7.2 degrees, SD 0.3–2.5) and this was significant compared to jigs LP1 and HP ($p < 0.026$). Jig HP was the least precise alignment method (7.2 degrees, SD 2.3) and this was significant compared to the two Lateral Pin jigs, jig NC2 and

Table 1 Guidewire alignment error

Alignment method	Mean coronal Alignment error (SD)		Mean version alignment error (SD)	
	Synthetic	Cadaveric	Synthetic	Cadaveric
LP1	−0.1 (4.5)	0.3 (2.8)	1.8 (5.9)	1.5 (3.2)
LP2	−1.8 (5.0)	−1.6 (2.3)	−4.1 (4.2)	−1.6 (3.0)
NC1	3.4 (5.7)	2.1 (3.1)	−1.0 (6.5)	−1.1 (3.5)
NC2	−4.7 (2.4)	−1.9 (2.0)	−0.3 (3.8)	−1.8 (2.6)
HP	2.4 (9.2)	−1.3 (5.3)	−4.9 (6.2)	−0.4 (3.6)
Navigation	0.2 (1.5)	1.1 (1.0)	−4.2 (3.8)	−0.1 (2.4)

*Negative values denote varus and anteversion

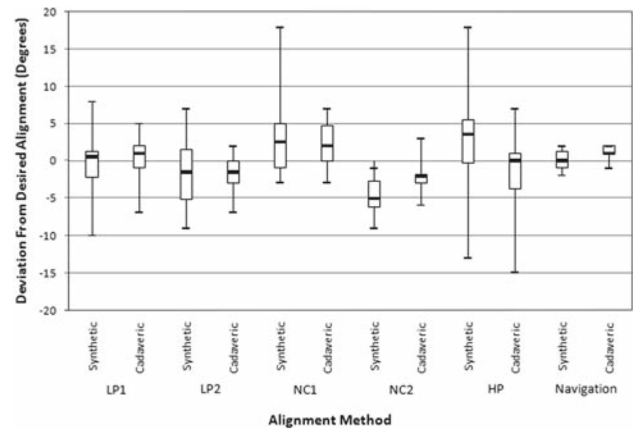

Fig. 1 Box and Whisker plot of coronal guidewire alignment angle error for synthetic and cadaveric femurs. Positive values represent valgus and negative values represent varus

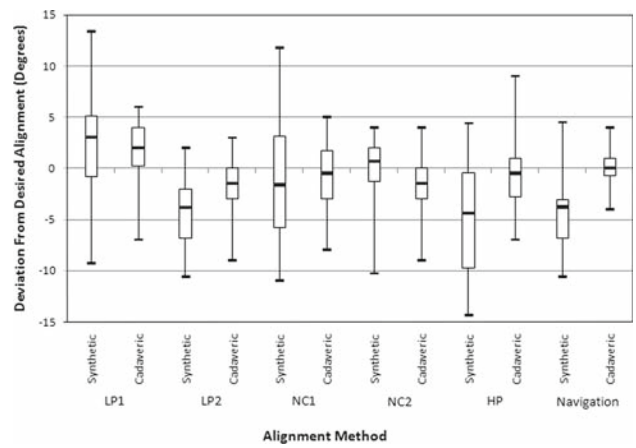

Fig. 2 Box and Whisker plot of sagittal guidewire alignment version error for synthetic and cadaveric femurs. Positive values represent retroversion and negative values represent anteversion

Navigation (1.3–3.2 degrees, SD 0.3–1.1, $p < 0.021$). There was no significant difference in guidewire version precision between the alignment method groups ($p = 0.299$).

Using cadaveric femora, there were significant differences in coronal alignment error between Lateral Pin jigs ($p = 0.027$) and between Neck Centering jigs ($p < 0.001$). Jig NC1 tended to place guidewires in valgus orientation compared to plan (mean 2.1 degrees, SD 3.1) and this was significant compared to all other jigs (1.9 degrees varus to 0.3 degrees valgus, SD 2.0–5.3, $p < 0.049$). Analysis of version error in cadaveric femora showed that Jig LP1 produced a mean version error of 1.5 degrees retroversion (SD 3.2) which was significantly different compared to the other jigs which tended to err in anteversion (0.4–1.8 degrees, SD 2.6–3.6, $p < 0.010$). Compared to Navigation (range −1–2 degrees coronal alignment error, −4–4 degrees version error), the range of error for the jigs was 3–7 times greater in coronal alignment error (Fig. 1) but similar in version error (Fig. 2). Coronal guidewire alignment accuracy was not dependent on femur specimen ($p > 0.377$), however, version accuracy was, as there were multiple differences in accuracy obtained between specimens ($p < 0.030$). Jig HP demonstrated significantly less precision than all other jigs in coronal guidewire alignment (6.3 degrees, SD 2.2,

$p < 0.023$) (Table 1). Similar to the synthetic femur arm of the study, there was no significant difference in guidewire version precision between the alignment jig groups ($p = 0.120$).

Conclusion

Correct alignment of the initial femoral guidewire is vital in avoiding malpreparation of the femoral head. The results of the current study demonstrate that there are differences in alignment accuracy obtainable between the different commercially available alignment jigs. Therefore, choice of alignment device may influence the accuracy of guidewire insertion ultimately impacting femoral component placement. Imageless computer navigation provided accurate and precise coronal placement of the initial femoral guidewire, superior to that of conventional guidewire alignment jigs, but yielded similar results in femoral guidewire version.

The influence of posterior tibial slope on antero-posterior stability in the ACL insufficient medial unicompartmental knee replacement

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Keywords Knee arthroplasty · Unicompartmental · Stability · Tibial slope

Purpose

Unicompartmental knee arthroplasty (UKA) is increasing in popularity as treatment of osteoarthritis in a single tibiofemoral compartment. It has been suggested that ACL function plays an important role in the successful outcome of UKA, with increased incidence of failure if the ACL is deficient. Traditionally it has been indicated that a functional ACL is necessary to ensure antero-posterior (ap) stability after UKA. To our knowledge there is no literature considering the role of posterior tibial slope on anterior tibial stability in the ACL insufficient medial UKA. Our hypothesis was that a decrease in posterior tibial slope will positively contribute to ap stability, in the ACL-insufficient medial UKA.

Method

We utilized twelve fresh-frozen, full-leg bilateral human cadaveric specimens, for computer assisted medial UKA implantation (Preservation, DePuy, J&J, Switzerland and Brain Lab, Germany). Posterior tibial slope of the component was chosen neutral (0°) on one side and physiologic (−5°) on the contralateral side and constantly controlled with the navigation system.. Dynamic and static stability prior and after implantation was assessed utilizing a customized navigated image free knee stability testing software (Praxim France) in combination with a customized biomechanical knee stability testing unit. Subsequently all specimens underwent transection of the ACL and measurements were repeated.

Results

Most noticeably the anterior drawer and Lachman exams in the ACL-insufficient Knees were influenced by reduction of posterior tibial slope. In the group with neutral (0°) slope the mean anterior translation was significantly reduced compared to the group with physiologic slope (−5°), with a mean anterior tibial translation of 5.7 mm and 9.2 mm, respectively ($p > 0.05$). With regards to rotational stability results were less apparent. Internal rotation increase from 23.5° to 24.9° (group 0°) and 23.9° to 25.6° (group −5°) respectively. External rotation increased from 20.7° to 23.4° and 18.8° to 24° respectively.

Conclusion

From our preliminary results we can conclude that increasing posterior tibial slope is undesirable in cases of underlying ACL-deficiency - it leads to excessive anterior translation and subluxation of the tibia. However, future studies are needed to show that reduction of negative posterior slope can effectively reduce ap and rotational instability in the weight-bearing model. Our data is evidence enough to conclude that one should avoid increasing slope in patients undergoing UKA where ACL-function is questionable.

Computer-assisted planning for mosaic arthroplasty

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Keywords Computer-assisted knee surgery · Cartilage reconstruction · Pre-operative planning · Mosaic arthroplasty

Purpose

Damaged articular cartilage in weight-bearing areas of the knee is not only painful for the patient, but also limits the Range of Motion (ROM) and therefore has a significant effect on the patient's quality of life. Because articular cartilage has a limited self-healing potential, surgical treatment is necessary to restore the cartilage surface. The transplantation of multiple autologous osteochondral plugs (mosaic arthroplasty) is one possible surgical technique. During this procedure, small osteochondral plugs are retrieved from the periphery of the femoralpatellar joint (or the margin of the intercondylar notch) and transplanted into damaged regions. For long-term success of this procedure, the transplanted plugs should reconstruct the curvature of the articular surface. To fulfill this requirement, many parameters including size, height, position, orientation and rotation of the plugs, as well as number and pattern of the plugs must be considered. This time consuming and complex geometric surgical intervention could profit from computer assisted navigation. Fundamental to the use of computer assisted navigation is the ability for accurate planning of the procedure. The goal of this study was to investigate whether preoperative CT based computer-assisted planning can accurately reconstruct the curvature of the articular surface.

Methods

Eight sheep were randomized into two groups, for left and right knee.

For each knee a CT scan was performed, immediately after an intra-articular injection of an contrast medium. All of these Arthro-CT were obtained with a LightSpeed Plus CT (GE Healthcare, Waukesha, USA) in axial mode, with a slice thickness from 0.625 mm at 140 kpV. During the scan the sheep were positioned as Feet-First-Supine.

Three-dimensional surface models for bone and cartilage were created, using the commercially available software package Amira (Visage Imaging, Inc., Carlsbad, CA, USA). The CT images were loaded and an initial automatic threshold segmentation were performed. These segmentations were manually refined using various editing functions, isosurface models for bone and cartilage created and saved.

In a minimal-invasive surgical intervention a cartilage defect on the medial condyle was impact-induced. Three months after this cartilage damage an additional Arthro-CT scan was obtained. These post-defect scans were performed using the same scanner and protocol as the pre-defect scans. Using the above described procedure, isosurface models for bone and cartilage were created.

Custom-made software was developed based on the freely available visualization library Coin3d (www.coin3d.org). For each knee the post-defect CT volume, as well as the 3d surface models for bone and cartilage, were loaded into the software and displayed to the user. The user identified the cartilage defect and created virtual cartilage plugs to reconstruct the articular surface. For each plug the radius,