INTRODUCTION
The motion of joints is described by means of a combined translational and rotational movement with respect to a fixed coordinate system. A rotation centre is defined as the point, which instantaneously immobile with respect to both the moved and fixed system. By using helical axes this will be well described. Helical axes reveal the hidden kinematics of a motion system like a “radiograph”. Helical axes combined with the morphology (fixed motion system) provide an excellent tool for experimental and clinical assessment and documentation of the joint kinematics. In this project the carpometacarpal joint of the thumb was analyzed by using the helical axes method. The aim of this project are to give better understanding about the kinematics of the biological joint especially the thumb joint, and to analyze the kinematics of the thumb joint. In the advance we are able to make a replacement of the joints.

MATERIALS AND METHOD
The left hands of the 2 test-persons were examined. The fixation device of the hand was made of the compressed wood (figure 6). The wood was chosen because it will not affect the magnetic field of the 3D-digitizer (Polhemus, Isotrak M100) used. This fixation was used to eliminate the side-movements of the hand during the experiment, and also to support the movement of the thumb in order to get the correct data for analysis. A computer-axiometry system (digitizer, Apple-computer Iic, software) was used to analyze the kinematics (position and direction of the finite helical axes, helical translation and rotation, and helical axes surfaces) of the carpometacarpal joint of the thumb (the joint between the trapezium and the 1st metacarpal bone, figures 3, 4 and 5). The thumb of the left hand was moved from the abduction to the adduction position and then from reposition to the opposition position (figures 7 and 8) while holding onto the fixation device. The complete movement was captured by the software (Tarsós® 2.0, Apple version)². This special software package collects the data and calculates as well as visualizes the helical axes parameters. The immobile system was the hand and the mobile one is the thumb. Four different data sets were taken for each left hand for each movement.

ANALYSIS
Any body undergoing a 3D-motion, is rotated about an axis and simultaneously translated along the axis. Helical axes parameters are position and direction of the finite helical axis, helical rotation, helical translation (thread) and the migration of the helical axis (helical axis surface). It also gives us the combined information of the changes in position and direction with helical angle. The helical axis surface can be combined with the fixed system in order to figure their correct position to each other.

The co-ordinate system used for the abduction-adduction analysis was: x pointing dorsally, y pointing radially and z pointing distally. The ab/adduction occurred about x-axis, the retro/anteversion occurred about y-axis and the re/opposition occurred about z-axis. For the reposition and opposition analysis the co-ordinate system used was: x pointing distally, y pointing radially and z pointing palmarly. The ab/adduction occurred about z-axis, the retro/anteversion occurred about y-axis and the re/opposition occurred about x-axis. The reference triangle ABC was parallel to the xy plane. After having printed the helical axes in the xy and xz planes, generated by the software (Tarsós® 2.0), the angle (“axis angle”) between the finite helical axes (of the different stages of the movement) and the reference coordinate system was measured. For both analyses the formulas below were used:

Angle of helical axis with x-axis in xy-plane: $\epsilon$ (epsilon)
Angle of helical axis with x-axis in xz-plane: $\eta$ (eta)

\[ \omega_x = (1+\tan(\epsilon)^2+\tan(\eta)^2)^{-0.5} \]

\[ \omega_y = \omega_x * \tan(\epsilon) \]

\[ \omega_z = \omega_x * \tan(\eta) \]

\[ (\omega_x^2 + \omega_y^2 + \omega_z^2)^{0.5} = 1 \quad (\omega_{res} = 1, \text{constant } \omega) \]

With:  
\( \omega_x \): angular velocity vector in x-axis 
\( \omega_y \): angular velocity vector in y-axis 
\( \omega_z \): angular velocity vector in z-axis
\[ T_x = \int \omega_x d\theta ; \quad T_y = \int \omega_y d\theta ; \quad T_z = \int \omega_z d\theta \]

With: 
- \( T_x \) = angular displacement about x-axis
- \( T_y \) = angular displacement about y-axis
- \( T_z \) = angular displacement about z-axis
- \( m \) = the maximum mean helical angle made by the thumb

Each set of analysis will have ten axes. It means that for each set of experiment the analysis step is one tenth of the max rotation angle of the corresponding movement. After measuring the angle between the finite axis, using the formula above, the unit angular velocity vector of each direction were calculated. The outcome from the calculation was used to find the polynomial regression of the data using Grapher 3.0. The integration of the polynomial function served to calculate the angular displacement of the helical motion.

The helical axis surface was reconstructed in AutoCAD2000, using the ACAD-script file provided by the software Tarsós 2.0 (figures 9 and 10).

RESULTS AND DISCUSSION

The graphs were plotted from the data that had been calculated earlier. Figure 1 shows the ab/adduction motion. It can be seen that the adduction motion is combined with the opposition and retroversion motion, while the abduction motion is combined with the reposition and anteversion. Figure 2 displays the re/opposition motion. The opposition is combined with the adduction and the anteversion motion, while the reposition is combined with the abduction and retroversion.

The position of the helical axis has to be seen with respect to the joint surface (figures 9 and 10). The direction of the helical axis indicates any automatic rotation of the joint. In this thumb joint for the example in the re/opposition movement the x axis represent the re/opposition motion. Any deviation from the horizontal direction is due to a hidden rotation (automatic or compulsory rotation) about a vertical or sagittal axis. The angle of the tilting will give us the information of the direction of the automatic rotation and of its relative as well as absolute amount (figures 1, 2, 11a, 11b, 11c). As can be seen from these figures the contribution of the main motion is much greater than the one of the simultaneous automatic motions.

The trapezium bone is characterized by the tubercle and groove which mark its rough, palmar surface. It has large, gently concave of the medial surface. The movement of the ab/adduction occur in the plane of axis of the ridge (the place in which fits the concavity of the 1st metacarpal base). The trapezial ridge is shorter than the corresponding metacarpal groove. Its surfaces are not completely congruent. Given the
specification above the trapezium significantly contributes to the mobility of the pollex. The metacarpal bones are miniature of the long bones, each possessing a rounded head, long shaft and an expanded base. The first metacarpal bone is shorter and stouter than the others. It lies on a more anterior plane and rotated medially round its long axis through the angle of 90°. By virtue of this position the thumb moves medially in front of the palm when it is flexed and it can be rotated into opposition with each of the fingers in turn. It is the most important factor in rendering the hand an efficient instrument forprehension. Such as grasping an object in the hand, the fingers encircle it on one side and the thumb from the other side, and the power of the grip increased very greatly thereby. From the results obtained, the range of re/opposition motion of the thumb is about 80°.

Noise reduction by the software and careful repeatability check are extremely important factors in order to reduce the error caused by the susceptibility of the helical axis to the measurement errors. The disadvantage of using helical axis that can also effects the results is because helical rotation is performed about the instantaneous helical axis. As vertebrate joint systems never are pure hinge joints, the axis migrates and tilts. Hence the total helical motion range doesn’t refer to a single, fixed axis. However, using the formula in the analysis section of this report, the absolute parts of the total helical motion about single axis can be calculated.

CONCLUSION
1. Helical axes reveal the hidden kinematics of a motion system and are the base of an exact motion analysis according to the presented interpretation guide. Helical axes combined with the morphology (fixed motion system) provide an excellent tool for experimental and clinical assessment and documentation of joints kinematics.
2. Helical axes help to determine the range and kinematics motion of the joint, so as to get the joint replacement.
3. The range of motion of the metacarpal joint of the thumb is ≈ 80° for re/opposition and ≈ 30° for ab/adduction.

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REFERENCES
APPENDIX

Figure 3: Carpal and metacarpal bones of the left hand. Palmar aspect.

Figure 4: The Os trapezium.

Figure 5: The first metacarpal bone.

Figure 6: Fixation device.

Figure 7: Reposition.

Figure 8: Opposition.

Figure 9: Combined picture of hand with the helical axes of motion from palmar view.

Figure 10: Combined picture of hand with the helical axes of motion from isometric view.

Figure 11: Angular velocity with respect to the helical motion of opposition/reposition motion, and polynomial regression (a: in the x-component of unit vector, b: in the y-component of unit vector, c: in the z-component of unit vector)