Modeling the Length of Wrist Ligaments

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Abstract: We hypothesize that there is a correlation between wrist ligament length disorders and wrist mobility disorders. In order to test that, we intend to add ligament length information to the existing wrist bone model developed at Brown. We will model the length of distal and scapholunate ligaments for a set of 18 wrists (9 of them with mobility problems), evaluate these lengths as functions of specific wrist movements, and compare the results. We will study the influence of variation of ligament insertion point location on ligament length. We expect that our results will lead to a better understanding of wrist mechanics, and possibly help diagnosing and solving wrist mobility disorders.

1. Introduction.

Diagnosis and treatment of wrist disorders are difficult tasks, given the little that is known even nowadays about wrist mechanics. The wrist project currently under development at Brown (figure 1) tries to remedy this situation by building a 3D model of the bones in the wrist and of their kinematics. However, not all wrist disorder cases benefit directly from this kind of pure bone information: according to a study performed at RI Hospital([1]), some patients display wrist mobility problems not associated with abnormal bone interactions. A plausible hypothesis is that these mobility problems are associated instead with carpal ligament disorders. The goal of our research is to test whether there is indeed, in such cases, a correlation between wrist mobility problems and ligament length disorders. The answer, either positive or negative, should help doctors set treatment guidelines for cases like the ones described above.

Unfortunately, CT data (on which the Brown bone model is based) reveal only bone information, and not much about ligaments (which are semisoft tissues). In theory, MRI could provide ligament information. Unfortunately again, the small size and complex anatomy of the wrist make such measurements difficult. For example, identifying one ligament in a particular knee only (which has a far simpler anatomy than the wrist) takes several months, according to Dr.Crisco, RI Hospital. Currently there is no such detailed MRI data available for the wrist, and there is no promise of immediate progress in this area.

We believe however that in fact CT and anatomy book data suffice in order to show whether there is a dependency between change in ligament length and change in wrist mobility. Ligaments could be modeled as minimal length paths between insertion points. The results of our 1999 experiment ([2]) seemed to confirm this hypothesis. We (naively) approximated the 2 distal radio-ulnar ligaments by polylines defined by control points, and evaluated the lengths of these paths as a function of wrist rotation angles.We expected drastic limitations of wrist mobility (characteristic to the patient we considered) to show drastic limitations of the ligament length, even taking into account the possible length-estimation errors due to the lack of appropriate MRI data. The surprising result was that, on the contrary, drastic limitations of wrist mobility were undoubtedly associated with abnormally increased ligament lengths (figure 2).

2. Specific Aims.

We intend to obtain a model of wrist ligament lengths. We will design an algorithm for building minimum length, surface-obeying paths, which will model ligament lengths. We will evaluate with the above algorithm the length of distal radio-ulnar ligaments and scapholunate ligament for a set of 18 wrists (9 of them with mobility problems) as a function of different patterns of carpal bone motion, and compare the results.We expect to find significant differences in ligament length between healthy and injured wrists.

In order to evaluate ligament lengths across different patients, we will need to find a generalized mapping of the locally parameterized bone model to the actual bones of each patient (see section 4 for details).

Finally, although the insertion points of the ligaments we consider seem to be pretty clear landmarks, we acknowledge that errors in identifying their exact location might influence the results of ligament length evaluation. Therefore we will perform a study on the influence of variation in ligament insertion point location on ligament length. We expect that small variations in the location of insertion points will lead to insignificant variations in ligament length.

3. Related Work.

There is little known about wrist ligaments, mostly because of the lack of appropriate study material. Current approaches are analyzing ligaments collected from cadavers ([3,4,5]) and “growing” bioengineered ligaments ([6]).However, these methods aim rather towards obtaining “transplantable” ligaments, and not towards understanding wrist mobility problems. Except for our 1999 experiment, there has been no other attempt so far of visualizing ligament lengths starting from data collected by noninvasive means.

On the other hand, building minimal length, collision-free paths is a common problem arising in robotics. Consequently, there are many papers on this topic, most of which approach this problem from a computational geometry point of view ([7,8,9,10,11]). Surface-fitting in general is also a popular topic; the bone model that we use is based on manifolds ([12]).

4. Methods.

Our work is based on the existing wrist-bone model developed at Brown, in collaboration with the RI Hospital. All the patients we consider experienced malunion of fractures of the wrist, and displayed wrist mobility problems unexplained by bone interactions. CT has been performed on both wrists of the patients, thus giving information about healthy and injured wrists, and in several standard positions of each wrist, thus giving information about changes in bone geometry during wrist movement. For the ligament length model, additional anatomy book data (such as insertion points and location/description of ligaments) is available.

Ligament length modeling

We are considering two possible approaches to the problem of building minimal length paths:

- the computational geometry approach: build minimal length, obstacle avoiding paths in 3D; parts of these paths should follow the edges of the bone-meshes. Similar approaches have been previously used in robotics. Problems: time complexity (dependent on the number of edges in the meshes considered); polyhedra corresponding to the bones are sometimes concave (most algorithms consider only convex polyhedra).

- the constraining approach: start with loose approximations of the curved paths and gradually constrain them. Problems: formulation of constraints; possible convergence problems?

Study of insertion points

We intend to slightly alter the location of insertion points by adding noise to their 3D coordinates and projecting the newly obtained points on the surface of the bones. We will reevaluate ligament lengths for these new insertion points, and compare the results.

Bone-fitting problem

Each carpal bone has a smooth, locally parameterized equivalent representation based on manifolds (figure 3). The manifold bones can presumably be fitted to bones coming from different patients (the model has been tested on only one patient, so far). The current fitting method starts by projecting actual data points (from a specific bone) onto the manifold bone (the “closest-point” approach). Although the shape of a manifold roughly corresponds to the one of the actual bone, from one patient to another bones may be slightly shifted, in which case the fitting process will fail. We will probably need to align the actual bones to the manifold bones first.

5. Timeline.

The estimated duration of our project is 11 months, with the following milestones:

4/15 - 5/15 Read related papers. Consider possible approaches. Detailed schedule.

5/16 - 6/30 Settle on a set of methods for generating minimal ligament lengths. Implement first method. Start drafting dissertation.

7/01 - 8/15 Evaluate distal ligament lengths across patient set. Deal with bone fitting problem.

8/16 - 9/30 Preliminary insertion point study. Evaluation of preliminary results.

10/01 - 11/30 Implement alternate method. Evaluate again distal ligament lengths.

12/01 - 01/15 Refine methods. Compare results.

01/16 - 02/15 Run algorithm on scapholunate ligament.

02/16 - 03/15 Finish dissertation.

Figures.

Figure 1.a) Carpal bone model. b) Forearm model.

Figure 2.a) Distal ligaments - healthy wrist. b) Distal ligaments - injured wrist.

Figure 3. Generating the bone model (hamate bone) a) the actual bone; b) the mesh generator; c) the manifold mesh, d) the fitted bone.

References: