

## Chapter 6

### Recommendations and Conclusions

The primary goal of this research was to design and construct a simplified wear testing apparatus for TKR materials, capable of quickly and inexpensively screening currently-available and new, alternative materials. The design criteria for the operational prototype were based upon the anatomy and motions of the healthy human knee as well as commercially available TKR.

Based upon preliminary assessment, all of the major components of the wear apparatus functioned consistent with the design specifications. Specifically, the frame structurally withstood the high magnitude stresses applied with negligible vibration and minimal displacement at the material interface. Albeit preliminary, it appeared that the pneumatic cylinder and valve were capable of reproducing the maximum force and loading curve experienced by implanted TKR. As specified, the stepping motors and linear tables simulated F/E, AP sliding, and cross shear. Lastly, all of the motions and loads were capable of user control and synchronization using a PC, motion control hardware, and Labview<sup>TM</sup> software.

Although not previously mentioned, one major advantage of the wear apparatus designed for this project is with its flexibility. Unlike the machines developed by Wang *et al.* (1999) and Blunn *et al.* (1991), the unique design and components initially selected for the designed device allow independent control as well as synchronization for multiple testing scenarios, including, but not limited to:

- AP sliding and F/E with physiologic loading,
- AP sliding and F/E under constant load,
- cross-shear with F/E under constant load,
- AP sliding only,
- F/E only,
- cross-shear only, and
- increased F/E angle, AP sliding distance, and load to simulate extreme cases.

Based upon the flexibility in input testing parameters, numerous combinations of motions and loads could be used to test materials for specific properties, or to determine the effects of these conditions and motions on the wear characteristics, among others. As just one example, suppose a new low-conforming TKR was in development and several new materials were being considered for the tibial bearing. Since AP sliding and contact stresses are increased in knees with low-conforming implants, these input parameters could be altered (i.e., increase sliding distance and maximum applied load) to better simulate physiological performance.

## **6.1 Recommendations**

Based on the outcomes from this design project, the following major modifications are suggested as methods to improve the accuracy, ease of use and performance of the designed wear apparatus:

- Closed loop feedback,
- Addition of a load cell,
- Measurement of the coefficient of friction,
- Improved user interface,
- Temperature control of the UHMWPE tray, and
- An extensive validation study of the device.

First, to ensure that F/E and AP sliding began at the same location for every cycle, closed loop feedback should be implemented. Closed loop feedback would also help to ensure that the stepping motors are moving smoothly between steps. Although it would be necessary to mount inexpensive optical sensors (Radio Shack) on the device, the motion control hardware is already capable of closed loop feedback. To simplify wiring and operation of the motor drivers for this project, it was initially decided to not include this feature in the designed system, however, this modification would improve repeatability and reduce the risk of damage to the device.

Second, the addition of a button-type load cell (Dillon, Fairmont, MN) placed under the UHMWPE specimen could be extremely beneficial. During force calibration, a load cell would be effective in accurately measuring the interfacial force for each of the

four stations separately. Currently, it is assumed that load is evenly distributed across the tray, but it is conceivable that this is not the case. More importantly, a load cell could measure the instantaneous force in each station through an entire loading cycle. With comparative information between the input and output loads, necessary adjustments could be made to the imported data file or to the upstream pressures to reach the optimal loading pattern.

It would also be beneficial to know the frictional forces between the bearing substrates. However, to obtain an accurate coefficient of friction would be difficult since the ideal location for measurement is on the F/E rods, which are constantly rotating during testing.

Fourth, the user interface could be improved. Ideally, the Labview™ VI would be capable of accepting:

- arbitrary motion curves for both AP sliding and cross shear,
- maximum and minimum interface forces and sliding distances,
- the operating frequency, and
- the test length.

In turn, the VI would:

- inform the user to what the cap end and valve pressures should be,
- adjust the motor velocities and accelerations automatically, and
- run the device for only the desired number of cycles.

Although the addition of these features would only simplify the adjustment of variables between different testing conditions, the efficiency of the device would be drastically improved.

Fifth, inclusion of temperature control within the UHMWPE tray would allow for better simulation of *in vivo* conditions. Although no conclusive evidence has shown differences in the wear of UHMWPE due to test temperature (i.e., ambient temperature and body temperature (37° C)), more accurate comparisons with tests from the literature could be made with the ability to adjust the testing temperature. One method to address temperature control of the lubricant could be to utilize a hot water bath and run several lines throughout the stainless steel tray .

Finally, the last recommendation is an obvious one. More testing is necessary under controlled conditions before any conclusions can be made about the capabilities of the designed device. Tests should be run in excess of one million cycles at 1 Hz, using polished CoCr (implant surface finish) and UHMWPE, and appropriately analyzed. Specifically, verification of wear rates, patterns and mechanisms produced with the designed apparatus in comparison to those clinically-observed still needs to be confirmed. Only after an extensive validation study has occurred can the device's effectiveness at simulating implant kinematics and predicting *in vivo* TKR wear be determined.

## **6.2 Conclusions**

The design and development of a wear testing device for TKR materials was a formidable, but rewarding challenge. Looking back at Table 3-1, all of our initial design specifications were accomplished. The designed device is capable of F/E up to 120°, AP sliding up to 25 mm, simulated tibial rotation at any angle, physiologically-correct loading up to 2.2 kN, continuous testing, and computer control of all loads and motions.

The project required a combination of several engineering disciplines. Machine design, static analysis, and finite element analysis of the frame, the tribological conditions at the material interface, instrumentation of the motion control hardware, programming of the user interface, and the anatomy and physiology of the human knee are just a few of the components of learning included in this project.

The developed device provides a useful apparatus for screening TKR materials and analyzing different modes of wear, with a flexibility only available with true knee simulators at a fraction of their cost (refer to Cost Analysis in Appendix F.). Although additional tests are necessary to determine the true capabilities of the device, its initial performance has been favorable. More importantly, the experience and knowledge gained through the device's development will directly contribute to the testing, development, and analysis of current and future total knee replacements and their materials.

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