Süleyman Demirel Üniversitesi
Fen Bilimleri Enstitüsü Dergisi

Suleyman Demirel University
Journal of Natural and Applied Science

18(SI: Biomechanics), 182-186, 2014

Test Bench Development for Femur Stability Assessment

Samuel SANCHEZ-CABALLERO*[1], Barbara LLINARES[1], Rafael PLA FERRANDO[1], Miguel A. SELLES[1]
[1] Universitat Politècnica de Valencia, Department of Mechanical Engineering and Materials, Alcoy, Alicante 03801, SPAIN

(Received: 12 September 2014, Accepted: 27 November 2014)

Keywords
Test bench
Femur fracture
Condylar fracture

Abstract: This paper shows the design and development of a test bench for human femurs. The main uses of this test bench will run from artificial femurs comparison with real femurs, to join stability assessment after bone a fracture repair. Among this uses is specially designed for condylar fractures testing. The test bench is developed from a self-made existing tensile/compression testing machine. The design procedure is supported by a literature review about the bone mechanical behavior and composition generally and the knee joint performance and repair particularly. On the basis of this review, the machine was designed to simulate the adduction and abduction movements of the joint. The magnitudes to be measured are: the compression force, the bone displacement (vertical) and the knee joint rotation.

1. Introduction

The main aim of this work is the design and development of a femur test bench to simulate the adduction and abduction movements to assess different fixation systems for femoral breakages. This test bench was built using the frame of a self-made tensile/compression testing machine used for composite testing purpose.

The test specimens are artificial bones from the company Sawbones which have been reported to have a similar mechanical behavior to human bones. Previous works reported a femur strength up to 1400 N and displacements up to 60 mm. These values were used to choose the force and linear and angular sensors. Once the test specifications were determined, a set of pieces where designed to carry out the test properly, allowing the femur bone to articulate in the same way that it does in the human body, allowing the adduction and abduction movements, depending on the test set up. This was achieved my means of a UHMWPE tibial insert supplied by Zimmer, Inc. which is used in total knee arthroplasty. Then, the sensors and designed parts were ordered and assembled on the tensile machine. Finally, the Data Acquisition System was developed, using an MGCplus DAQ from the company HBM. The Data Acquisition set up is made through an executable OPG programmed with Catman 5.0

2. Materials and Methods

2.1. Distal femoral fractures

Bone fractures can be grouped in two types: acute or traumatic fractures and fatigue fractures. The first are associated to punctual overloading owed to falls and traumas. The second ones are caused by repeated loading on a certain part of the bone, usually associated to endurance sports where the muscular fatigue avoids the load absorption, overloading the bone.

Distal femoral fractures on the knee (condylar and supracondylar) have been found to occur from 4 to 7% of the femoral fractures and its repairing it's considered a challenge (Kolmert et al., 1982). There are two main groups of patients suffering this fracture: elderly women and a small but significant group of young people with high energy traumas. Elder patients have usually weak osteoporotic bones.

Osteoporosis is a systemic disease characterized by bone mass loss with a subsequent damage of the bone microarchitecture, increasing its brittleness and the fracture risk. During the growing period the resorption rate is lower than the ossification rate, producing the bone growing. However, between thirty and forty the resorption rate is higher the ossification rate causing the subsequent negative balance of bone mass.

Amenorrheic women have even higher resorption rates due to hormonal imbalance caused by a lower estrogen production (Jonnavithula et al, 1993) which could explain why elderly women are more affected by these fractures. The pattern and severity of the fracture varies significantly. Often fracture occurs through simple bending and/or compression of the

---

* Correspoinding author: sasanca@dimm.upv.es

condyles, however, splitting of the condyles by patellar wedging is possible, especially if the knee is highly flexed during impact (Pacific Research Laboratories, 2007; O'Connor et al., 2008).

2.2. Condylar fractures fixation

The fixation of condylar fractures can be especially challenging. The bone can be highly damaged, and the fracture often passes through the articular surface of the condyle, making proper fixation crucial (Martín Águila, 2010). The fragmented bone fixation can be done with different devices. Smaller fragments may be secured with bone screws while larger comminuted fractures are often treated with either intramedullary nails, locking plates, or dynamic compression plates and screws (Chong et al., 2007).

The American Orthopedics Foundation provides a wide classification of fractures throughout the body to aid surgeons in diagnosing and treating patients. Also publishes an online interactive AO Surgery Reference which provides the classifications for bone fracture and recommends fixation options (Colton et al., 2011). Most of the recommended fixation procedures use bone screws and plates to fix the bones. Figure 1 shows one of these fixation methods.

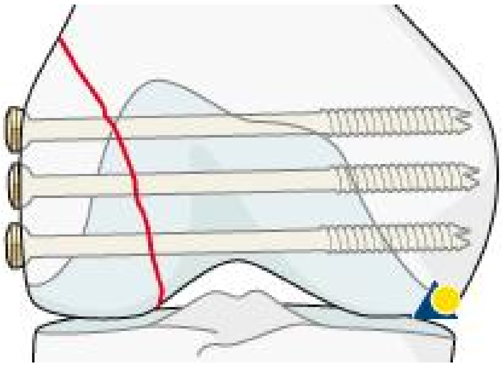

Figure 1. Image of a B1-type fracture of the lateral femoral condyle. Open reduction for large fragment, good bone quality, and low demand patient. With permission of AO Foundation. Copyright© by AO Foundation, Switzerland.

2.3. Bone fixtures

In order to simulate anatomical loading, two fixtures used to axially load the foam femora were designed. The upper fixture consisted of a block of ultra-high-molecular-weight polyethylene (UHMWPE) with a hemispherical cavity machined into it that closely matched the dimensions of the femoral head. Like a natural hip socket, the fixture allowed for femoral head rotation but kept it centered in the load frame. The lower fixture included a UHMWPE tibial insert (used in total knee arthroplasty; Zimmer, Inc.).

The UHMWPE allows the required friction force between the femoral and tibial parts. In this work, the friction coefficient between the artificial bone and the polyethylene insert was 0.1376 (Prygoski et al., 2013), which is nearly similar to friction between human bone and articular cartilage in quasistatic conditions (Sardinha et al., 2013).

2.4. Bone fixtures support

The upper fixture support (Fig. 2) is joined to the load cell, model 333A-100 supplied by Ktoyo, responsible to measure the load transferred to the femur. The maximum error of the load cell is 0.03%.

Figure 2. Upper fixture support.

The lower fixture support allocates the tibial insert, reproducing the knee rotation, allowing the abduction and adduction behavior. For this purpose, the tibial insert was attached to a cradle (Fig. 3) that was allowed to rotate about the anterior-posterior axis (Fig. 4-5). The rotational axis intersected an imaginary line defined by the contact points of the condyles and, in a manner similar to the upper fixture, was centered in the load frame. The ability of the fixture to tip or rotate allowed for load sharing between the intact and fractured condyles (Viano et al., 1980). The cradle rotation is measured through a rotation encoder model E6C2-CWZ1X 2000P/R 2M supplied by OMRON with a resolution of 2000ppr.

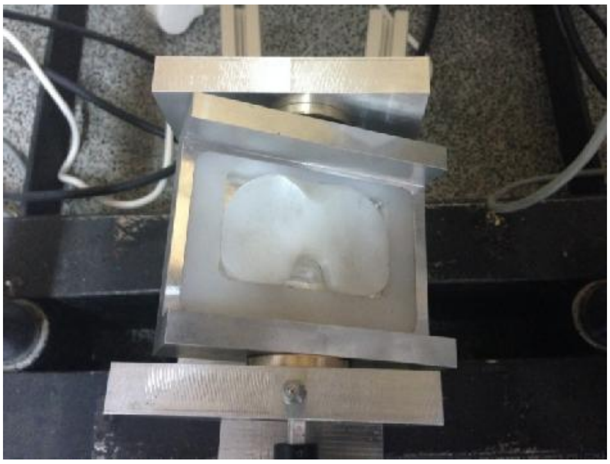

Figure 3. Tibial insert and cradle.

Figure 4. Lower fixture support.

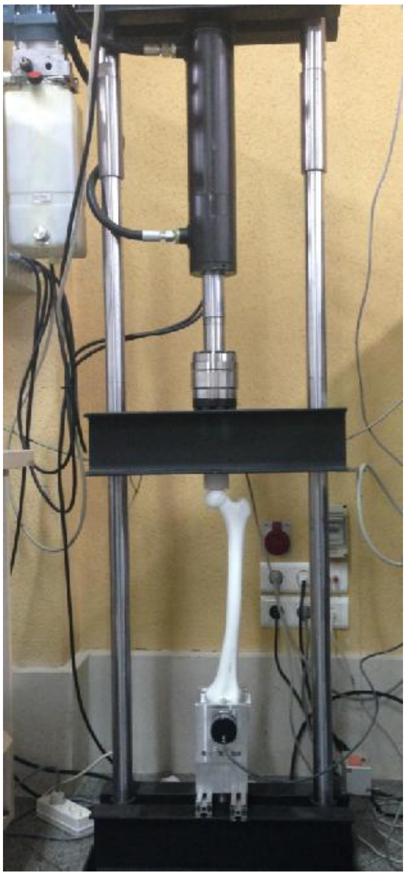

Figure 5. Compression machine with femur fixtures.

2.5. Data Acquisition System

The data measured by the sensors is read by a general purpose Data Acquisition System (DAS) model MGCplus supplied by HBM. The equipment can measure up to sixteen analogic cards and eight channels per card. The sampling frequency can yield *to 19.2 kHz per channel with a maximum resolution of* 20 bit. Figure 6 shows the DAS. The DAS set up is made through the software Catman, supplied by HBM.

2.6. Artificial femur bones

Human femora are usually employed to assess the behavior of surgical and orthopedic components, seeking mostly to compare the load transference over the implant stability. However, the wide variety of human specimens represents a problem as there are required a high number of samples to obtain satisfactory results (Cristofolini et al., 1996). Moreover, the use of cadaveric bones remains a problem due to its availability, handling and conservation.

In 1992 the UTA (University of Texas Arlington group) proposed a simple bone model made of polyurethane to assess different fixation procedures. Other researchers proposed other models with anisotropic properties (McKellop et al., 1991, Ypma et al., 1982). However, the first commercial artificial bone was supplied by Pacific Research Labs (Sawbones) (Cristofolini et al., 1996). Till then, four generations of artificial bones have been developed.

The fourth generation of artificial bones is made of a short glass fiber with epoxy matrix composite to simulate the cortical bone, and polyurethane foam as cancellous bone. The mechanical behavior of the artificial bones subjected to axial, bending and torsional loads is quite similar to human femora as has been reported (Heiner et al., 2001; Chong et al., 2007).

As previous research support the use of artificial bones as good substitute for human femora, they were used to validate the bench test.

Figure 6. Data Acquisition System.

3. Results

Intact Sawbones were tested to validate the test bench. Once the test was completed it was noted that all the elements and devices of the test bench worked properly. Figure 7 shows the relationship between force and displacement for such test.

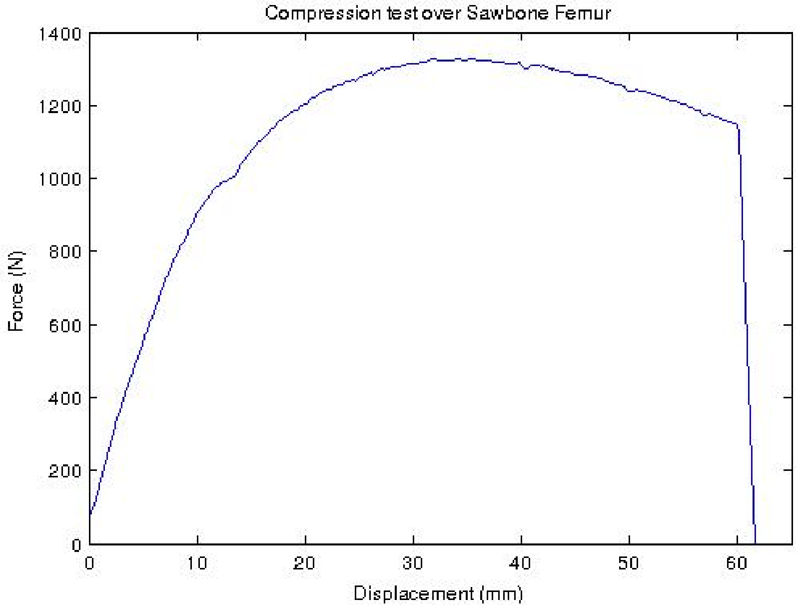

Figure 7. Compression force vs. femur displacement.

The femoral force fracture is consistent with previous works (Alho et al., 1988; Stankewitz et al., 1996), which reported break forces from 725 to 10570 N, while the fracture location is also coherent with a compression overload over the femoral neck. Figure 8 shows the femoral neck fracture of the test specimen

Figure 8. Subtrochanteric femoral neck fracture

4. Discussion and Conclusion

Once the test bench was built, the tests made with artificial bones show that the force versus displacement relationship is consistent with previous reported works made with human bones, validating the test bench and the use of artificial bones to such purposes. After the test bench validation, the next step will be assessment of different join systems to fix distal femur fractures in order to compare and optimize them.

Acknowledgements

The authors wish to acknowledge the support of the Generalitat Valenciana and the Universitat Politècnica de Valencia through the grants GV/2013/046 and PAID-06-12 respectively.

References

Alho A, Husby T, Hoiseth A. Bone mineral content and mechanical strength. An ex-vivo study on human femora at autopsy. Clin Orthop Rel Res 1988;227:292–297.

Chong, A.C.M., Friis, E.A., Ballard, G.P., Czuwala, P.J., Cooke, F.W. Fatigue performance of composite analogue femur constructs under high activity loading, 2007. Annals of Biomedical Engineering, 35 (7), pp. 1196-1205.

Chong, A.C.M., Miller, F., Buxton, M., Friis, E.A., 2007. Fracture toughness and fatigue crack propagation rate of short fiber reinforced epoxy composites for analogue cortical bone. Journal of Biomechanical Engineering, 129 (4), pp. 487-493.

Colton, C., Gebhard, F., Kregor, P., and Oliver, C., 2011. AO Surgery Reference: Distal Femur. AO Foundation, accessed 20 January 2011, www.aofoundation.org.

Cristofolini, L., Viceconti, M., Cappello, A., Toni, A., 1996. Mechanical validation of whole bone composite femur models. Journal of Biomechanics, 29 (4), pp. 525-535.

Heiner, A.D., Brown, T.D., 2001. Structural properties of a new design of composite replicate femurs and tibias. Journal of Biomechanics, 34 (6), pp. 773-781.

Jonnavithula, S., Warren, M.P., Fox, R.P., Lazaro, MI., 1993. Bone density is compromised in amenorrheic women despite return of menses: a 2-year study. Obstet Gynecol. 81(5 (Pt 1)):669-74.

Kolmert, L., Wulff, K., 1982. Epidemiology and treatment of distal femoral. Acta Orthop Scand. 1982 Dec;53(6):957-62.

McKellop, H., Ebramzadeh, E., Niederer, P.G., Sarmiento, A., 1991. Comparison of the stability of press-fit hip prosthesis femoral stems using a synthetic model femur. J. Orthop. Res. 9, 297–305.

O'Connor, L.M., Davidson, J.A., Davies, B.M., Matthews, M.G. and Smirthwaite, P, 2008. Comparative endurance testing of the Biomet Matthews Nail and the Dynamic Compression Screw, in simulated condylar and supracondylar femoral fractures.

Pacific Research Laboratories, 2007. 4th generation composite bones have improved fracture and fatigue properties. Informational handout.

Prygoski, M.P., Sanchez-Caballero, S., Schmid, S.R., Lozier, A.J. and Selles, M.A. High Speed Fracture Fixation: Assessing Resulting Fixation Stability and Fastener Withdrawal Strength, 2013. Journal of Biomechanical Engineering, 135 (9), art. no. 091008

Martín Águila, A., Ruiz Caballero, D.J., Brito Ojeda, D.E. and Jiménez Díaz, D.J., 2010. Prótesis de rodilla. Biomecánica. XXIV Jornadas canarias de traumatología y cirugía ortopédica

Sardinha, V.M., Lima, L.L., Belangero, W.D., Zavaglia, C.A, Bavaresco, V.P., Gomes, J.R., 2013. Tribological characterization of polyvinyl alcohol hydrogel as substitute of articular cartilage, Wear, Volume 301, Issues 1–2, April–May 2013, Pages 218-225, ISSN 0043-1648, http://dx.doi.org/10.1016/j.wear.2012.11.054.

Stankewitz CJ, Chapman J, Muthusamy R, et al. Relationship of mechanical factors to the strength of proximal femur fractures fixed with cancellous screws. J Orthop Trauma 1996;10:248–257

Viano, D. C., and Stalnaker, R. L., 1980. Mechanisms of Femoral Fracture. J. Biomech., 13, pp. 701–715