Acta of Bioengineering and Biomechanics
Vol. 2, No. 2, 2000

Mechanical and medical aspects of an implant–bone connection in the femur: A three-dimensional photoelastic study of the load transfer mechanism using gamma radiation for fixing the experimental information. Comparison of two solutions of femur prosthesis

R.J. BEER and J. EBERHARDSTEINER

Technische Universität Wien, Adolf Blamauergasse 1–3, A 1030 Wien, Austria

J. KODVANJ

University of Zagreb, Croatia

W. GRIENAUER

Austrian Research Centre, Seibersdorf, Austria

F. GOTTSAUNER-WOLF and G. von SKRBENSKY

Universitätsklinik für Orthopädie, AKH-Wien, Währingergürtel 18–19, A 1090 Wien, Austria

Key words: implant–bone connection, load transfer, the Viennese and Bologna models

The investigation of the implant–bone connection is of significant surgical interest as the postoperative course is influenced by the primary stability of the connection. It is necessary to achieve primary stability, so that the patient can be mobilized as soon as possible without any additional orthopaedic treatment. The achievement of the so-called secondary (longtime) stability through an ingrowth of bone is only possible if a perfect fixation of the implant is reached during surgical treatment. In this paper two different types of prosthesis, called Viennese and Bologna models are investigated. The reason for this investigation is given by the fact that these two types present two different fixing techniques developed for long bones. The main difference between the two solutions is given by the kind of implantation and its influence on the stress distribution in the load transfer area. In suitable models the stresses in the close vicinity of the load transfer areas are compared in both implant types using suitable photoelastic models.

1. Introduction

The ingrowth of the bone and the resultant achievement of the secondary (long-time) stability are suppressed by a peak pressure causing reactive bone resorption as well as by an incomplete fit which leads to loosening of the connection because of possible local micro-movements [1]. Therefore the distinguishing feature of this connection is an equal transfer of load over as wide as possible area and avoidance of too large stress gradients. The dominant force when standing and walking is a pressure on the connection. However, some movements of the flexed knee cause a torsion moment. That means that also an adequate torsion stability of the connection must be guaranteed [2]. In addition, torsion may also cause axial loosening (screw effect) of the connection before secondary stability is reached, as the muscle tension is too weak or medically eliminated during operation and in the wake-up phase.

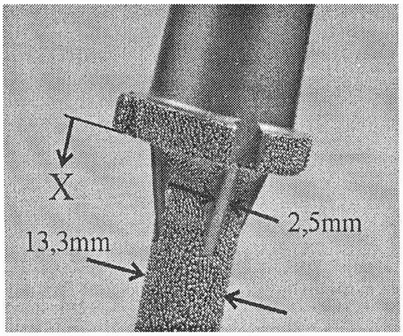

Fig. 1. Viennese model

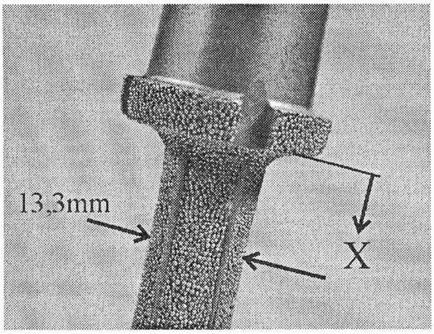

Fig. 2. Bologna model

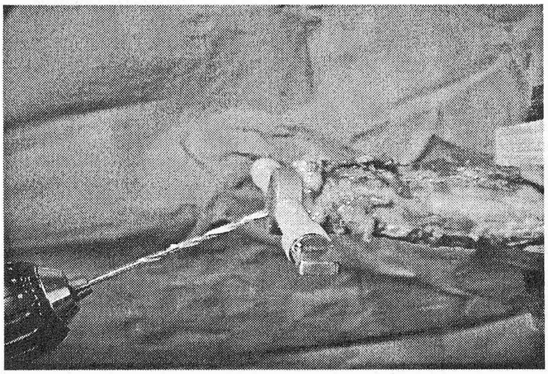
Fig. 3. Tool for preparation of the femur

In the Viennese model, the transfer of pressure as well as a torsion loading of the connection are carried out by a strong conical-shaped head of the implant which is relatively short with four large rips on it (figure 1). The rips should fit accurately in the bone marrow after some preparation with a special tool (figure 3), so that the prosthesis can be put in without any excessive force (stressless form-fit). In the Bologna model (figure 2), on the other hand, the slightly shaped head of the implant is much longer and equipped with five small and very sharp ribs which carve the inner cortical bone layer in order to prevent rotating. This model needs implantation forces and causes stresses already due to the implantation of it.

In both cases some additional, even more serious, problems arise due to the asymmetric form and the dimension of the femur.

2. Experimental procedure

The stress distribution in the load-transfer areas was investigated using three-dimensional photoelasticity. However, due to the fact that the models consist of two parts with different mechanical and thermal properties any thermal treatments must be avoided. Therefore a new method for fixing the photoelastic fringes was used [3], [4]. It consisted in applying gamma-radiation to partially polymerized Araldite B which was hardened by means of malein acid anhydride.

Analyzing the experimental results one has to keep in mind that the photoelastic model does not fit in with the reality. Therefore, it is not possible to transfer the results to the original by using similarity laws. However, for the comparison of the load transfer mechanism for different types of protheses the photoelasic results are a very useful basis.

a b

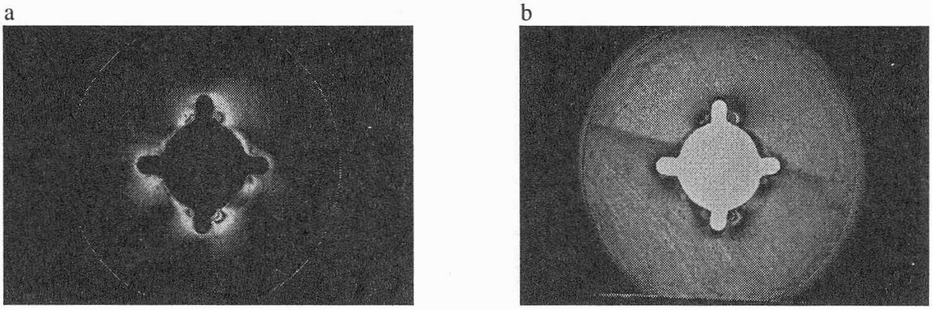

Fig. 4. Typical fringe distribution caused by the fixing stresses only for the Viennese model (a – dark field, b – bright field)

Figures 4 and 5 show typical fringe distributions for the Viennese model (taken in a dark-field and a bright-field polariscope) caused by the fixing stresses only and by the superposition of the fixing and loading-stresses (torque moment M_t = 6 dNm). These figures show also the contour of the ribs of the Viennese model. Figures 6 and 7 show the same for the Bologna model. The contour of the ribs of this model is triangular with a very sharp ridge.

a b

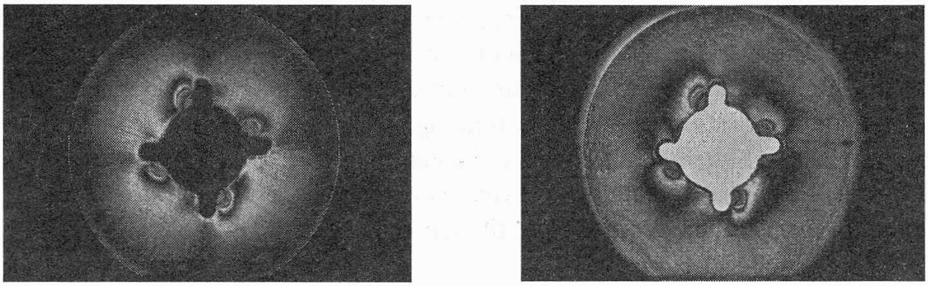

Fig. 5. Typical fringe distribution caused by the fixing and loading stresses for the Viennese model (a – dark field, b – bright field). Torque moment $M_t = 6$ dNm

a b

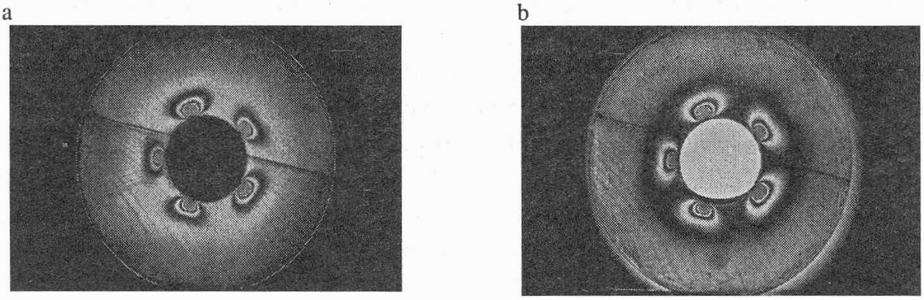

Fig. 6. Typical fringe distribution caused by the fixing stresses only for the Bologna model (a – dark field, b – bright field)

a b

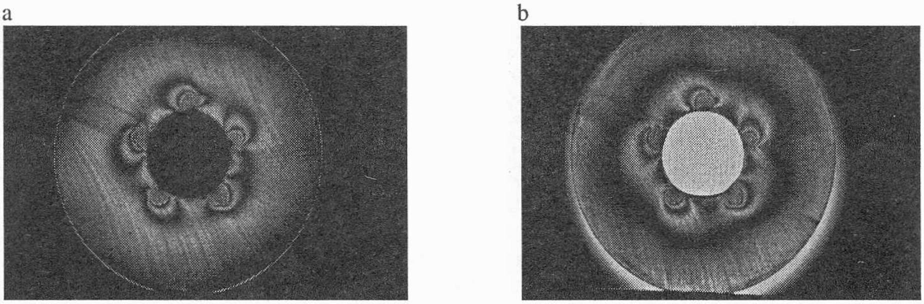

Fig. 7. Typical fringe distribution caused by the fixing and the loading stresses for the Bologna model (a – dark field, b – bright field). Torque moment $M_t = 6$ dNm

A comparison between these figures gives the following result. Even in the Viennese model (figures 4 and 5) it was not possible to avoid the fixing stresses completely. However, due to the fact that they are much less than those produced by the Bologna model (figures 5 and 7) it may happen that because of the bleeding during operation (and even afterwards) those stresses might not be able to prevent the connection from an axial loosening which is a serious problem before reaching its final stability.

A comparison with the corresponding figures for the Viennese model shows that there is a big difference in the magnitude and the distribution of the respective stress fields. In the case of the Bologna model, the fringe patterns in a close vicinity of the ribs are quite similar to those around an opening crack. Taking account of the fact that the cross-section of a femur is not circular, we cannot expect that all ribs of the Bologna model are in an equal contact with the femur which means that an additional stress concentration effect may occur in reality.

3. Analysis of the fringe information and some conclusions

Figures 8 and 9, concerning the Viennese model, show the axial distribution of the normalized fringe order *n*/*d* as a function of *x* (see figures 1 and 2) in the vicinity of the contact area. Figures 10 and 11 show the same in the case of the Bologna model. In both cases only those fringes that are easily distinguishable are taken into account. That means that these figures show only the situation in the elastic zone of contact area.

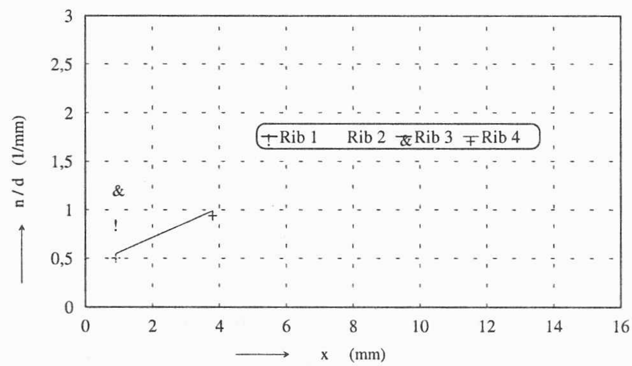

Fig. 8. Viennese model (mounting stresses):
n – fringe order, *d* – thickness of the slice, *x* – position

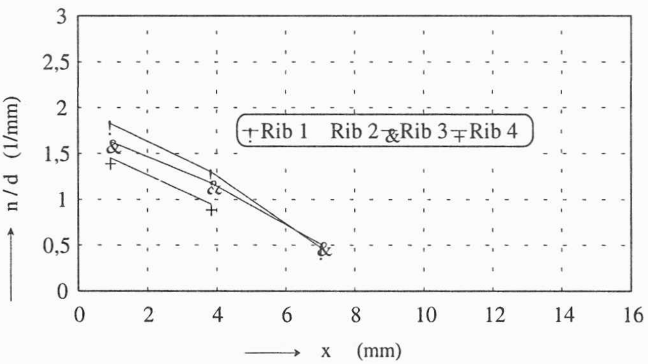

Fig. 9. Viennese model (with torque moment $M_t = 6$ dNm):
n – fringe order, *d* – thickness of the slice, *x* – position

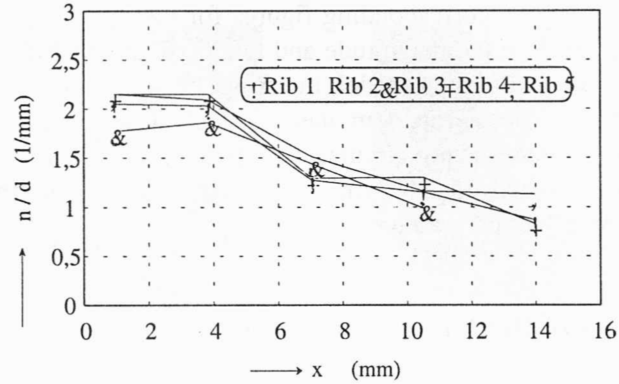

Fig. 10. Bologna model (mounting stresses):
n – fringe order, d – thickness of the slice, x – position

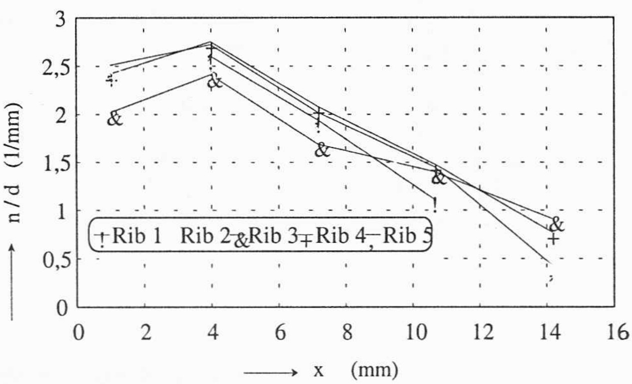

Fig. 11. Bologna model (with torque moment $M_t = 6$ dNm):
n – fringe order, d – thickness of the slice, x – position

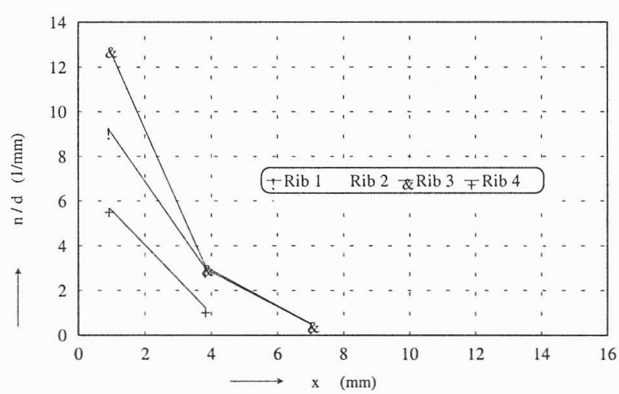

Fig. 12. Viennese model (extrapolation into the region of non-countable fringe orders): n – fringe order, d – thickness of the slice, x – position

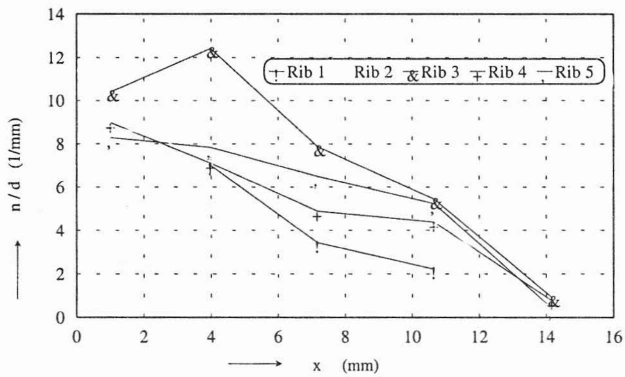

Fig. 13. Bologna model (extrapolation into the region of non-countable fringe orders): M_t = 6 dNm, *n* – fringe order, *d* – thickness of the slice, *x* – position

Figures 12 and 13, concerning both models, show the result of a quadratic extrapolation procedure into the region where the fringe numbers for some reason (for instance partial plasticity in the vicinity of the sharp ribs of the Bologna model) are hardly to detect.

A comparison between figures 8 and 10 and between figures 9 and 11 proves that there exists a significant influence of the different load transfer mechanism. However, the most significant is the effect due to a non-equal contact between the ribs and the bone (non-perfect form fit between the femur and the prosthesis), especially in the case of the Viennese model. This effect is caused by a usual asymmetric form of the femur in the areas of relatively high mounting stresses in the vicinity of the ribs having the first contact. Especially figures 12 and 13 show this effect clearly.

Literature

[1] GOTTSAUNER-WOLF F., PLENK Jr., H., *Die Knochenverankerung von Tumorendoprothesen mit angegossenen Kügelchen aus Kobalt-Basislegierung*, Orthopädie, 1987, 16, 252–257.

[2] MARKEL M.D., GOTTSAUNER-WOLF F., ROCK M.G., FRASSICA F.J., CHAO E.Y. S., *Mechanical characteristics of proximal femural reconstruction after 50% resection*, The Journal of Orthopaedic Research, 1993, Vol. 11. No. 3, pp. 339–349.

[3] BEER R.J., WENDRINSKY J., GRIENAUER W., JECIC S., *Three-dimensional photoelasticity using new radiation cured polymers*, Proc. of the 12th Danubia-Adria Symposium, Sopron (Hungary), 5–7 Oct., 1995.

[4] BEER R.J., KODVANJ J., GRIENAUER W., SCHAUDY R., *Different treatments of radiation-cured and their influence on the long-time behaviour*, Proc. of the 15th Danubia-Adria Symposium, Bertinoro, Forli (Italy), Sept. 30 – Oct. 3, 1998 .