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Static analysis of annuloplasty rings sutured on an annulus model of
the mitral valve: comparison between the Duran ring and the
Carpentier Classic ring

Abstract A novel in vitro evaluation system was developed
to study the performance of newly developed and conven-
tional annuloplasty rings. Using this system, a comparative
study between the Duran flexible ring and the Carpentier
Classic (rigid) ring was conducted with the aim of achieving
a better understanding of these devices and of providing
surgeons with better criteria for selecting the most appro-
priate annuloplasty ring. It was possible to obtain quantita-
tive data using a microscope and a load cell to measure
valve orifice area and tensile load on the valve annulus,
respectively. Among the results were the findings that the
orifice area of the rigid ring was smaller by 12.0% than that
of the flexible ring and that in both rings the load was
greater in the posterior region than in the anterior region.
Further analysis using a beam model demonstrated that the
stress applied to the sutures of the rigid ring is higher than
that for the flexible ring in terms of shearing force and
bending moment of the ring. This pilot study yielded several
important findings: the ability of a ring to maintain valve
orifice area is observable; larger loads are applied to the
posterior annulus than to the anterior annulus; and it is
possible to clarify and compare the characteristics of vari-
ous types of annuloplasty rings.

Key words In vitro evaluation system · Duran ring ·
Carpentier ring · Load on the annulus

Introduction

In comparison to prosthetic heart valve replacement, valvu-
loplasty for mitral insufficiency has reduced the incidence
of thromboembolism and does not require anticoagulant
treatment for most patients in the late postoperative pe-
riod.1 It is accepted that the various types of clinically avail-
able annuloplasty rings can reliably prevent recurrence of
regurgitation, although their functional characteristics vary
widely as a result of differences in material and design.2
Currently, the characteristics of these annuloplasty rings are
discussed only subjectively, based on clinical data using
transesophageal echocardiography or other methods.3–5
Therefore, it is important to provide surgeons with objec-
tive comparative data that could assist in choosing the most
appropriate annuloplasty ring for a given patient. With this
goal in mind an in vitro evaluation system for annuloplasty
rings has been developed, the validity of which was demon-
strated in a previous study.6-7 The aim of the present study is
to compare the characteristics – under static conditions – of
two typical annuloplasty rings in current clinical use by
means of the in vitro evaluation system.

Materials and methods

Annuloplasty rings tested

In the Duran flexible ring (flexible ring, hereinafter), silicone
rubber containing barium sulfate is used as the core, providing ample flexibility. Because of this feature, physi-
ological annular motion should be achieved after valve
repair. Also, excessive suture stresses can be mitigated.
In the Carpentier–Edwards Classic ring (rigid ring, here-
inafter), a titanium core is covered with polytetrafluoro-
ethylene (PTFE), which has limited flexibility. This allows
the largest valve orifice area to be secured in the diastolic
phase, thus remodelling the valve orifice to its normal size
and shape.8
Test apparatus

Figure 1 shows a schematic of the test apparatus developed in the Umezu Laboratory of Waseda University. Our model of the mitral valve orifice, to which the annuloplasty ring is sutured, was made from a latex rubber sheet (Kyowa, Osaka, Japan) with a thickness of 1 mm. Based on an actual porcine heart, this model anatomically mimics the shape of the natural mitral valve orifice and realistically accommodates suturing of the annuloplasty ring to the annulus. Essentially, it is a flat sheet cut to anatomically mimic the crescent shape of the cuspal coaptation zone developed during mitral valve closure and thus it has no leaflet contact area or valve function. With regard to the material properties of this model, the Young’s modulus, as found from a tensile test, was close to that of the natural mitral valve tissue as reported by Kunzelman et al. We adopted a mitral valve orifice area of 5.0 cm$^2$ or larger for the model so as to accommodate installation of annuloplasty rings with nominal diameters of 35–36 mm, as currently offered by most manufacturers. A Duran flexible annuloplasty ring (Medtronic, Minneapolis, MN, USA) with a nominal diameter of 35 mm and a Carpentier–Edwards Classic ring (Edwards Lifesciences, Irvine, CA, USA) with a nominal diameter of 36 mm were tested. For each test the ring was sutured into the model by an experienced cardiac surgeon using multiple mattress stiches.

To form a valve orifice, an element that applied a load to the free margins of the leaflet was required. For this purpose, surgical sutures were attached to the free margin of the mitral orifice model. The total number of sutures was four: two sutures for the anterior leaflet and two for the posterior leaflet. This system forms a lumped parameter model of the natural chordae and papillary muscles and its only role is to develop a valve orifice. As a result, neither the physiological behaviour nor the actual number of cords is simulated. The material used for these cords was 2-0 Ethibond polyester sutures (Ethicon, Somerville, NJ, USA), which has a Young’s modulus greater than the natural chordae, and was adopted to improve the orifice area response relative to the applied load.

A hollow aluminum shaft (Nippon Light Metal, Tokyo, Japan) with an inner diameter of 2 mm and an outer diameter of 3 mm was used as the connection element between the load cell and the test piece, aiming to improve the reproducibility and reliability of the data acquired; the hollow shaft insignificantly influenced the tare weight to the load cell because its weight was only about 1.4 g, whereas the resolution of the load cell was approximately 5.0 g. To permit adjustment of the zero-load point, the shaft was provided with a fine thread and a hook was attached to the other end (the test-piece side), as shown in Fig. 1.

Fig. 1. Schematic of the evaluation system for annuloplasty rings developed at Waseda University