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Research Paper

Viscoelastic properties of a spinal posterior dynamic stabilisation device

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ABSTRACT

The purpose of this study was to quantify the frequency dependent viscoelastic properties of two types of spinal posterior dynamic stabilisation devices. In air at 37 °C, the viscoelastic properties of six BDyn 1 level, six BDyn 2 level posterior dynamic stabilisation devices (S14 Implants, Pessac, France) and its elastomeric components (polycarbonate urethane and silicone) were measured using Dynamic Mechanical Analysis. The viscoelastic properties were measured over the frequency range 0.01–30 Hz. The BDyn devices and its components were viscoelastic throughout the frequency range tested. The mean storage stiffness and mean loss stiffness of the BDyn 1 level device, BDyn 2 level device, silicone component and polycarbonate urethane component all presented a logarithmic relationship with respect to frequency. The storage stiffness of the BDyn 1 level device ranged from 95.56 N/mm to 119.29 N/mm, while the BDyn 2 level storage stiffness ranged from 39.41 N/mm to 42.82 N/mm. BDyn 1 level device and BDyn 2 level device loss stiffness ranged from 10.72 N/mm to 23.42 N/mm and 4.26 N/mm to 9.57 N/mm, respectively. No resonant frequencies were recorded for the devices or its components. The elastic property of BDyn 1 level device is influenced by the PCU and silicone components, in the physiological frequency range. The viscoelastic properties calculated in this study may be compared to spinal devices and spinal structures.

1. Introduction

Between 1998 and 2008, US hospital charges, for spinal fusion, increased from $4.3 billion to $33.9 billion (Rajaee et al., 2012). Spinal fusion is the gold standard surgical treatment of low back pain caused by degenerative disorders (Schwarzenbach et al., 2010; Sengupta, 2004; van den Broek et al., 2012b) even though many problems such as prolonged recuperation time, adjacent segment degeneration and pseudarthrosis are associated with it (Serhan et al., 2011). To alleviate these problems, non-fusion techniques have been suggested as an alternative (Serhan et al., 2011) and Posterior Dynamic Stabilisation (PDS) devices, in particular, are rapidly evolving for spine surgery (Khoueir et al., 2007; Serhan et al., 2011).

The BDyn device (S14 Implants, Pessac, France) is a PDS device that provides an alternative to fusion. This bilateral

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PDS device is designed to preserve intersegmental range of motion, reduce intradiscal pressure and alleviate loading of the facet joints. It can be used in the bridging of one segment level (vertebra-disc-vertebra) or multiple segment levels. The BDyn device consists of two elastomeric components, a mobile titanium alloy rod, a fixed titanium alloy rod, and it is fixed to the vertebrae by titanium alloy pedicle screws (Fig. 1). The interaction of the mobile rod and the elastomeric components allows partial three-dimensional spinal movement. An *in vitro* study of the BDyn device showed that the device was successful in limiting the range of motion of the L4–L5 segment following laminectomy (Guerin et al., 2011). The device has also been used in the treatment of degenerative lumbar spondylolisthesis (Gille et al., 2014).

Factors, such as age, whole body vibration, lifting, twisting, psychosocial factors, and low educational status have been associated with low back pain (Hoogendoorn et al., 2000; Hoy et al., 2010). Alongside heavy and frequent lifting, long term vibration exposure was stated as a high risk factor of low back pain (Magnusson et al., 1996). Numerous studies have evaluated the effect of vibration and quantified the viscoelastic properties of the spinal structures *in-vitro* (Gadd and Shepherd, 2011; Holmes and Hukins, 1996; Kasra et al., 1992; Zhou et al., 2014) and *in-vivo* (Panjabi et al., 1986; Wilder et al., 1982). Others have investigated the dynamic stiffness of spinal implants (Benzel et al., 2011; Dahl et al., 2011; LeHuec et al., 2003), while Gloria et al. (2011) quantified the dynamic viscoelastic properties of a disc prosthesis.

Viscoelastic properties can be quantified by numerous testing methods which include creep, stress relaxation and Dynamic Mechanical Analysis (DMA). Unlike conventional creep and stress relaxation tests, DMA is a dynamic testing method used to determine the viscoelastic properties of a material or multi-component structure. For DMA, the viscoelastic properties are measured following the application of an oscillating force to a specimen and analysis of the out-of-phase displacement response (Menard, 2008). A viscoelastic structure can be characterised in terms of a storage and loss stiffness. The storage stiffness represents the elastic portion of the viscoelastic structure and it describes the ability of a structure to store energy, while the loss stiffness characterises the ability of the structure to dissipate energy through heat and internal motions (Menard, 2008).

In the seated position, the human lumbar spine has been reported to be resonant from 4–5 Hz (Panjabi et al., 1986; Wilder et al., 1982), thus, it is important to understand the frequency dependant behaviour of these viscoelastic spinal implants, its components, and assess how these implants behave at spinal resonant frequencies. The purpose of this study was to measure the viscoelastic properties of the BDyn PDS spinal implants and its elastomeric components using DMA. Comparisons were made between the elastomeric components and the devices to assess if a particular elastomeric component had an influence, or had a dominant effect, on the viscoelastic properties of the device.

2. Materials and methods

Six BDyn 1 level, six BDyn 2 level PDS devices, six silicone and six polycarbonate urethane (PCU) components (Fig. 2) were obtained from S14 Implants (Pessac, France). All devices and elastomeric components were sterilised using ethylene oxide (EtO) (Steriservices, Bernay, France).

The viscoelastic properties of the BDyn devices and its components were measured using a Bose ElectroForce 3200 testing machine running Bose WinTest 4.1 DMA software (Bose Corporation, Electroforce Systems Group, Minnesota, USA). The DMA technique, machine and software have been previously used to quantify the storage and loss modulus or stiffness of numerous biological tissues (Barnes et al., 2015; Espino et al., 2014; Omari et al., 2015; Wilcox et al., 2014) and polymers (Mahomed et al., 2008). Custom-designed grips were used to clamp the titanium alloy rods and/or titanium alloy elastomer housing of the BDyn device and the devices were secured by 12 horizontal screws (Fig. 3).

For testing of the BDyn 1 level and BDyn 2 level devices, the titanium alloy mobile and fixed rods were gripped (Fig. 3a and b). The BDyn device is designed to work in both tension and compression, therefore, a sinusoidally varying load of

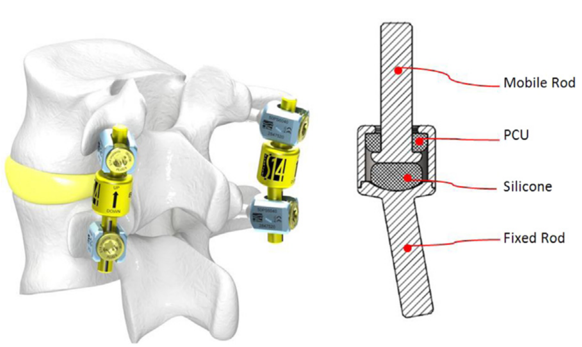

Fig. 1 – BDyn 1 level fixed to the vertebrae (Left) [Reproduced with kind permission from S14 Implants, Pessac, France. ©S14 Implants] and cross sectional view of the BDyn device (Right). The mobile rod, fixed rod, polycarbonate urethane (PCU) and silicone component are highlighted.

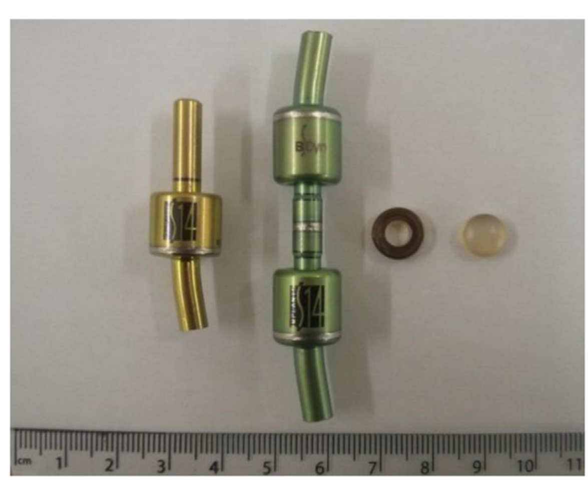

Fig. 2 – From left to right; BDyn 1 level (BDyn 1), BDyn 2 level (BDyn 2), polycarbonate urethane (PCU) component and silicone component.