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# Effect of embedded optical fibres on the mechanical properties of cochlear electrode arrays

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ABSTRACT

Incorporating optical fibres in cochlear electrode arrays has been proposed to provide sensors to help minimise insertion trauma and also for the delivery of light in optical nerve stimulation applications. However, embedding an optical fibre into an electrode array may change its stiffness properties, which can affect the level of trauma during insertion. This report uses measurements of buckling and deflection force to compare the stiffness properties of a range of cochlear electrode arrays (Nucleus straight array, rat array, cat array and guinea pig array) with custom arrays containing an embedded optical fibre. The cladding diameters of the optical fibres tested were 125 μm, 80 μm and 50 μm. The results show that the stiffness of the optical-fibre-embedded arrays is related to the diameter of the optical fibre. Comparison with wired arrays suggests optical fibres with a diameter of 50 μm could be embedded into an electrode array without significantly changing the stiffness properties of the array.



## 1. Introduction

Over the past 30 years, cochlear implants have helped many recipients who have severe to profound deafness to hear [1,2]. The cochlear implant system consists of a microphone, speech processor, transmission system, stimulator and an electrode array that is implanted into the cochlea [1]. The electrode array plays a crucial role in activating the auditory neurons [3].

The cochlea is an extremely delicate structure. Therefore, while cochlear implants have proven to be an effective intervention, there has been an ongoing effort to identify ways of minimising any potential trauma to the cochlea due to the electrode array insertion process [4-9]. The interested reader is directed to references [1,9] for a more detailed description of the cochlear anatomy. Damage to the basilar membrane and to the spiral ligament at the outer wall of the scala tympani are some negative outcomes potentially associated with the insertion of cochlear implant electrode arrays [3,9,10]. Injury to the functional peripheral dendrites or spiral ganglion cells during insertion can lead to reduced efficiency of the cochlear implant system [11]. Insertion trauma can also effect the positioning of the cochlear electrode [12] which may impair performance. Recently there has been a growing trend of cochlear electrode implantation in partially deaf patients [13]. These patients commonly have good low frequency hearing [14]. The importance of atraumatic implant insertion is increased due to the desire to preserve this hearing as it has been shown to improve speech recognition in noisy environments and the appreciation of music [13-18].

Improved implant designs and insertion techniques have significantly reduced the potential for insertion trauma [19]. In order to further reduce the instances and/or extent of insertion trauma there has been interest in including sensors in the electrode array to provide real-time feedback to the surgeon, or as part of a robotic insertion tool [20,21]. Feedback could include information on the force, position and/or curvature of the electrode array during the insertion process [9,22-27]. Optical fibre sensors embedded into the electrode array may be able to provide this feedback and therefore help to reduce insertion trauma [9].

Optical fibres are thin light guiding structures typically made from silica glass. The most well-known use of optical fibres is in telecommunication applications, however they are also widely utilised in sensing devices [28]. Common single mode optical fibre has three layers: the innermost light guiding layer is the glass core, which is surrounded by a glass cladding and an outer protective acrylate coating, as shown in the inset of Fig. 1.

In general optical fibre sensors have advantages of being safe, flexible, small, and reliable [28]. Optical fibre sensors can be used to sense

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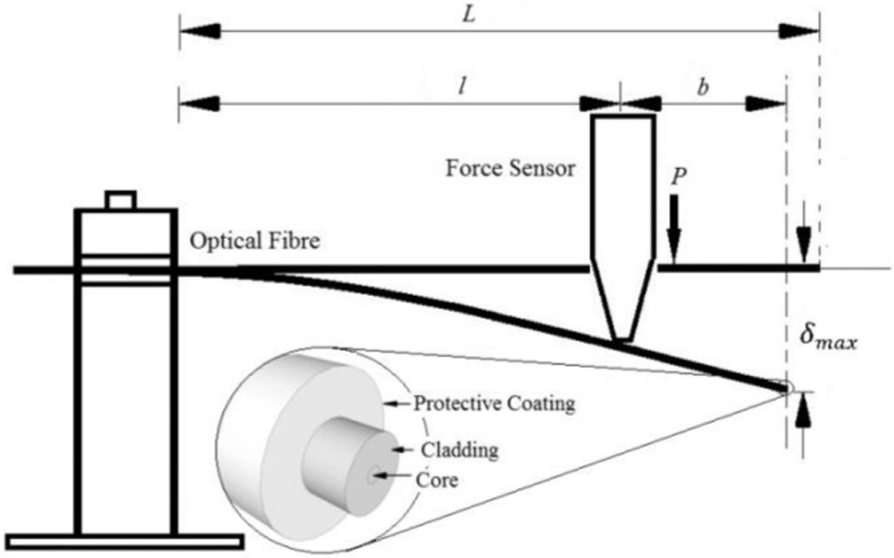


**Fig. 1.** Cantilever beam test configuration showing the parameters used in testing and calculating the theoretical stiffness of the beam. Inset shows the optical fibre structure (not to scale).

a variety of parameters including strain/force, temperature and bending [28]. For example, an optical fibre Bragg grating sensor embedded in a cochlear electrode array has been used to monitor the force acting on the tip of the array [9]. Optical fibre has also been suggested as an acoustic sensor within the cochlear implant allowing for a completely implantable system [27] and has been proposed to deliver light for optical stimulation of the cochlea [29-31]. Recently Balster and co-workers investigated the insertion forces of optical fibres in a cochlear model and also human temporal bones in relation to optical stimulation [32]. They found that the insertion forces in the model and trauma in temporal bones both reduced with smaller fibre diameters.

The stiffness of cochlear electrode arrays has been shown to be related to the amount of subsequent insertion trauma [3,4,6,7,11,33]. The stiffness of an electrode array affects its ability to withstand deformation [34] and takes into account the Young's modulus, shape and boundary conditions of the material(s) with which the array is made. For example, finite element modelling has suggested that the Nucleus straight array design may be less likely to create insertion trauma compared to the Nucleus contour array design (both by Cochlear Ltd) [3]. The Nucleus straight array has a graded stiffness [33], which reduces the contact pressure exerted by the tip of the electrode array [4].

Embedding an optical fibre into an electrode array may change its stiffness properties. Therefore this work aims to compare the stiffness properties of optical-fibre-embedded electrode arrays with conventional cochlear electrode arrays and also with a number of custom arrays used in animal trials. In the embedded optical fibre arrays, the electrode wires were replaced with optical fibres with diameters in the range of 50–125 μm. This study aims to clarify what changes to mechanical properties result from incorporating an optical fibre into an electrode array.

## 2. Theory

The stiffness properties of cochlear electrode arrays can be investigated by looking at the deflection and buckling forces. These forces represent the transverse and longitudinal forces acting on the electrode arrays during insertion.

### 2.1. Deflection force

The deflection force, $P$ is the force required to deflect an object a certain distance, $\delta_{max}$, as shown in Fig. 1. This force is directly related to the stiffness of an object, as it is this force that overcomes the object's resistance to deflection. Measurements of deflection force have previously been used to determine the stiffness of cochlear electrode arrays [7,11,33]. For example, Kha et al. [33] showed that the stiffness of the Nucleus straight array (Cochlear Ltd) varies along the length of the array.

The deflection force of the electrodes can be modelled according to the cantilever beam theory [35] for a concentrated load, $P$, applied on the beam at any point. The experimental arrangement used for deflection force testing in this work is shown in Fig. 1. The deflection distance, $\delta_{max}$, for a given force, $P$, applied at a location $l$ along a beam of total length $L$, can be calculated using [35]:

$$\delta_{\max} = [(Pl^2)/(6EI)](2l + 3b), \quad (1)$$

where $E$ is Young's modulus (72.5 GPa for silica fibre [36]) and the moment of inertia, $I$, is given by

$$I = \frac{\pi d^4}{64} \quad (2)$$

for a beam of diameter $d$. See Fig. 1 for further explanation of the relevant parameters.

This theory is based on a small bending approximation which in reality is not completely appropriate for this work. In particular, assumed uniform beam stiffness and diameter, excludes the effects of friction (between array/fibre and force sensor) and assumes that the bending angle is very small, whereas the angle used is relatively large (up to 30°). As such a more general theory was derived to better match the actual test case. This theory is referred to as the derived theory in this paper. For more information on the derived theory, please refer to the supplementary material, S1.

### 2.2. Buckling force

The buckling force is the force required to buckle/bend a beam (e.g. the electrode array) when it is subjected to a compressive force in the longitudinal direction (see Fig. 2). Patrick and MacFarlane [7]