Measuring the Elastic Properties of Fine Wire

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Received 16 March 2001; revised 2 July 2001; accepted 5 July 2001

Abstract: The elastic moduli of fine wires made from MP35N and 304SS used in implantable biomedical devices are assumed to be the same as those published in the literature. However, the cold working required to manufacture the wire significantly alters the elastic moduli of the material. We describe three experiments performed on fine wire made from MP35N and 304SS. The experimentally determined Young's and shear modulus of both wire types were significantly less than the moduli reported in the literature. Young's modulus differed by as much as 26%, and the shear modulus differed by as much as 14% from reported values. © 2001 John Wiley & Sons, Inc. J Biomed Mater Res (Appl Biomater) 58: 694–700, 2001

Keywords: MP35N; 304 SS; Young's modulus; shear modulus; strain

INTRODUCTION

The fine wires used in medical devices are made from a variety of metals and alloys including, but not limited to, MP35N, stainless steel, nitinol, titanium, and tantalum. The authors' laboratory utilizes MP35N (ASTM F562) (MP35N is a trademark of SPS Technologies, Inc.) (a cobalt–nickel alloy) for cardiovascular applications because it has high strength and good corrosion resistance.[1] 304SS is used for prototyping and initial setup and testing of new equipment. Although the bulk properties of both alloys are well known,[2–4] the wire is put through a wire drawing process that reduces the size from approximately 12.7-mm OD to 0.0254-mm OD.

In order to perform testing and validation on products made from these thin metal wires, several basic materials properties of the metals are required: Young's modulus (E), shear modulus (G), and Poisson's ratio (ν). (If any of the two are known the third can be calculated.) Altman, Meagher, Walsh, and Hoffman[5] reported the results of fatigue testing on MP35N wire and coils. However, their calculations were based on E and G values (236 and 81 GPa, respectively), which resulted in a calculated Poisson's ratio of 0.46. Although 0.46 is a correct calculation derived from an exact relationship, the number is clearly wrong (as a general rule, Poisson's ratio is about 0.33 for metals[6]) and should have served as a warning that E and/or G were incorrect for the wire. (Soft metals, like lead, have a ν of 0.45.) Our own tensile testing of MP35N wire (0.127 mm) provided an E value of 169 GPa (unpublished data), which is significantly below the reported value of 235 GPa.[2] It was concluded that the difference could be due to either the extremely small size of the wire and/or the wire drawing process. This discrepancy led to the question of what the correct values for E, G, and ν are in extremely fine, cold-drawn wires.

This article does not attempt to provide correct elastic properties for all of the different types of metal wires used in medical devices. Instead, this report discusses three different, nonstandard tests that were developed to determine wire diameter, Young's modulus, and shear modulus of fine wire made from virtually any material.

MATERIALS

All wire was purchased from Fort Wayne Metals (Fort Wayne, IN) and used in the as-received condition. The following was tested: MP35N wire: 0.102-, 0.127-, 0.152-, 0.178-, 0.203-, and 0.229-mm outside diameter (0.004-, 0.005-, 0.006-, 0.007-, 0.008-, and 0.009-in. OD, respectively), and 304SS wire: 0.0762-, 0.127-, 0.178-, 0.203-, and 0.229-mm outside diameter (0.003-, 0.005-, 0.007-, 0.008-, and 0.009-in. OD, respectively).

METHODS

Wire Diameter

In order to determine E and G of a wire sample, the diameter of the wire must be known precisely. As will be demonstrated later, wire diameter raised to the fourth power is used to

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calculate the shear modulus. A small variation in wire diameter results in a large variation in G. An optical technique, which measured the positions of fringe minima of a diffraction pattern (generated by laser light obstructed by a wire placed under tension,) was used to determine the diameter of the wire.

If a source of planar light (i.e., a laser beam) passes through an aperture of a width on the same order of magnitude as the wavelength of the light, a Fraunhofer diffraction pattern will be produced.[7] By Babinet's theorem,[7] the Fraunhofer diffraction pattern produced by a rectangular mask (in this case the profile of the wire) will be identical to the diffraction pattern produced by a rectangular aperture of the same width (with the exception of some minor pattern differences near the center of the diffraction pattern). As the width of the mask decreases, the distance between the minima and the center of the diffraction pattern increases. By measuring the minima shift, and knowing the wavelength of the laser, the width of the mask (the wire diameter) can be calculated.

When the diffraction pattern is projected onto a screen, the diameter of the wire d is

$$d = \frac{m\lambda}{\sin\theta}, \tag{1}$$

where θ is the angle between the minima and the laser beam, m is the minima number (counting out from the center), and λ is the wavelength of the laser.[7] If s is the distance between the wire and the screen, and a is the distance separating opposite minima of the diffraction pattern,

$$a/\sqrt{s^2 + a^2}$$

can be substituted for sin θ in Eq. (1), giving the following:

$$d = \frac{1}{a} m\lambda \sqrt{s^2 + a^2}. \tag{2}$$

The wire sample was mounted horizontally on a workbench so that the wire was approximately 2.5 cm above the surface of the bench. One end of the wire was mounted to a movable stage, which allowed the tension in the wire to be adjusted. A 10-mW 634-nm helium–neon laser was placed approximately 1 m behind the wire. The emission aperture was placed level with the wire and as far behind the wire as possible, so that the width of the beam near the wire was large enough to center the beam over the wire easily. This procedure helped to eliminate the possibility of edge wave diffraction effects. To obtain wire diameter, the distance a separating opposite minima of the diffraction pattern was measured. By measuring the distances between five pairs of minima (the center of the minima were used), the diameter of the wire was calculated from Eq. (2). To ensure that the diameter of the wire was uniform, measurements of the wire diameter were taken at two locations on each wire, with each location separated by about a meter. Measuring any one pair of fringe minima is sufficient to calculate wire diameter. However, five separate pair of minima were measured at each of two sections of wire, giving a total of 10 measurements.

Young's Modulus

The modulus of elasticity (Young's modulus) of a bar (or wire) in simple tension or compression is the constant E that relates the axial stress σ with the strain ϵ in the equation

$$\sigma = E\epsilon. \tag{3}$$

The measurement of the Young's modulus consisted of applying a known force to a section of wire and then measuring the resulting longitudinal elongation of the wire.

One end of the wire was clamped to a workbench so that the wire was mounted horizontally, approximately 2.5 cm above the workbench. The clamp consisted of simple opposable smooth-faced jaws, which, when closed, pinched the wire between the faces. (This arrangement is identical to that used on standard tensile testers.)

A digital force sensor was attached to the other end of the wire. The force sensor was mounted to the workbench on a movable micrometer stage, in order to measure the applied axial force on the wire. The unstretched wire was marked 0.75 m from the clamp. By changing the position of the stage (which changed the axial force applied to the wire), the displacement of the leading edge of the mark was observed with the use of a traveling microscope. (The same edge of the mark was measured each time.) From these displacement measurements, the axial strain on the wire was calculated.

The force sensor used in this experiment was equipped with a computer interface so that each recorded force measurement was actually the mean of 600 individual measurements. With this instrument, the axial force was measured with a standard deviation of less than 0.014 Newtons. The longitudinal elongation of the wire was measured to a precision of 0.01 mm with the traveling microscope. The initial length of the wire (the distance between the immobile clamp and the ink-mark) was measured to 1.0 mm.

For each wire sample, force was applied in increments of approximately 0.5 Newtons; force and displacement measurements were recorded at each increment. The axial forces were kept below 20 Newtons (the maximum limit of the force sensor), and the axial strains were kept below 0.4% elongation [Plastic deformation is generally assumed to occur for most metals at strains of around 0.2%.[4] However, from the published Young's modulus and yield strength of MP35N (2.38×10^{11} Pa and 1.5×10^{9} Pa, respectively), plasticity would not be expected to set in until strains of 0.63% were reached.]. The Young's modulus of each wire sample was calculated with the use of a least-squares analysis on 15 sets of data pairs. The experiment was repeated four times for each type of wire, with a fresh piece of wire used in each experiment.

Shear Modulus

The shear modulus of elasticity of a material G relates the stress τ with the strain tensor ε in the equation

$$\tau = 2G\varepsilon. \tag{4}$$

Here, the strain tensor is defined as

$$\varepsilon_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right), \tag{5}$$

where u_i is the displacement in the i direction.[8]

The shear modulus of the MP35N and 304SS wires were measured with a torsion pendulum. A torsion pendulum is the angular version of a simple harmonic oscillator where a mass (usually a flat disk) is suspended from a wire. When the mass is rotated by a small amount, it will oscillate within the horizontal plane. To measure the shear modulus of a wire, an expression relating the shear modulus to the period of oscillation of the pendulum is needed.

Consider a cylinder of length L and radius r, in a rectangular coordinate system. The base of the cylinder is fixed in the xy plane, and the axis of the cylinder runs along the z axis. A couple is applied to the other end of the cylinder (at $z = L$) such that the moment is orthogonal to the xy plane. The cylinder twists so that the planar cross sections of the cylinder orthogonal to the z axis remain plane, orthogonal to the z axis, and at the same z positions.

If a couple is applied to the end of the cylinder at $z = L$, the planar section at z will rotate by the action of the couple through an angle θ, and the adjacent plane, $z + dz$, rotates through an angle $\theta + d\theta$. If the material is homogeneous and the deformations are kept below the elastic limit, then the rotation per unit length α can be assumed constant, and that $d\theta = \alpha\ dz$. A point at x, y, $z + dz$ will be rotated by the accumulated deformations of the planes between $z = 0$ to $z < z + dz$ through an angle θ, plus the rotational deformation of the plane itself, $d\theta$. The components of the infinitesimal displacement of the point x, y, $z + dz$ due to the rotational deformation $d\theta$ are

$$du = -y\ d\theta \tag{6}$$

$$dv = x\ d\theta, \tag{7}$$

$$dw = 0, \tag{8}$$

where u, v, and w are the displacements in the x, y, and z directions, respectively. Equations (6) and (7) can also be written as

$$\frac{\partial u}{\partial z} = -y\alpha \tag{9}$$

$$\frac{\partial v}{\partial z} = x\alpha, \tag{10}$$

or

$$\varepsilon_{xz} = -\frac{1}{2}y\alpha \tag{11}$$

$$\varepsilon_{yz} = x\frac{1}{2}\alpha, \tag{12}$$

where ε_{ij} is the strain directed in the i direction with a normal in the j direction. In this coordinate system, ε_{xz} and ε_{yz} are pure shear strains with resulting stresses

$$\tau_{zx} = 2G\varepsilon_{xz} = -Gy\alpha \tag{13}$$

$$\tau_{zy} = 2G\varepsilon_{yz} = Gx\alpha. \tag{14}$$

Note that this result assumes the material is both isotropic and homogeneous.

The moment of the couple M_z lies along the z axis and relates to the shear stresses by

$$M_z = \int\int (x\tau_{zy} - y\tau_{zx})\ dx\ dy \tag{15}$$

$$= G\alpha \int\int (x^2 + y^2)\ dx\ dy \tag{16}$$

$$= \frac{G\alpha\pi r^4}{2} \tag{17}$$

$$= \frac{G\theta\pi r^4}{2L}. \tag{18}$$

When a bar is suspended at the end of the wire and a rotational force is applied to the wire, by Newton's second law, Eq. (18) becomes

$$\left(\frac{\partial^2\theta}{\partial t^2}\right) I_{\text{total}} = \frac{G\theta\pi r^4}{2L}, \tag{19}$$

where I_{total} is the sum of the moments of inertia of the wire and the bar. The moment of inertia of the wire (with the axis of rotation along the z axis) is

$$I_{\text{wire}} = \frac{1}{2}\rho L\pi r^4, \tag{20}$$

where ρ is the mass density of the wire. Integrating Eq. (19) and solving for the period T gives

$$T = 2\pi\sqrt{\frac{I_{total}}{G\pi r^4/2L}}. \tag{21}$$

Note that $I_{total} = I_{wire} + I_{bar}$, so Eq. (21) can be solved for the shear modulus,

$$G = \frac{4L\pi(\rho L\pi r^4 + 2I_{bar})}{T^2 r^4}. \tag{22}$$

The moment of inertia of the bar is relatively difficult to measure accurately if the moment of inertia of the device used to attach the bar to the wire is to be included. To compensate for this, Eq. (22) can be modified so that only the difference in the moment of inertia, I_{add}, between two different trials needs to be known in order to calculate the shear modulus:

$$G = \frac{8L\pi}{r^4}\left(\frac{I_{add}}{T_2^2 - T_1^2}\right). \tag{23}$$

Here T_1 and T_2 are the periods of oscillation of the pendulum before and after the moment of inertia has been increased. If two weights are added near the ends of the bar, the moment of inertia of each weight does not need to be known to great precision [By the parallel-axis theorem, when m is the mass of each weight and l is the distance between the axis of rotation and the center of mass of the weight, $I_{add} = 2(I_{weight} + ml^2)$. The ml^2 term can easily be made an order of magnitude greater than the moment of inertia of each weight.]. The effect of the expected diameter contraction of the wire resulting from the addition of weights on the pendulum is negligible.

The torsion pendulum consisted of an aluminum bar with a mass of 21.6 g and a length of 15 cm, suspended from a wire sample approximately 20 cm long. The length of wire varied between tests but was measured to 0.5 mm. The pendulum was rotated from its equilibrium position, and the time required for the pendulum to complete five oscillations was measured with a stopwatch. The moment of inertia of the bar was increased by adding two small weights (with a mass of 12.2 g each) to opposite ends of the bar so that the inner edge of each weight was 7.0 cm from the center of mass of the bar. The period of oscillation of the pendulum was remeasured with the same stopwatch. By using the two measured periods and Eq. (23), the shear modulus of the wire was calculated. The moment of inertia of each weight at a distance of 7.9 cm from the axis of rotation was 7.85×10^{-5} kg m^2, and the moment of inertia of each weight with the axis of rotation through the center of mass of the weight was approximately 1.75×10^{-6} kg m^2. Two wire samples from each batch of wire were tested, with five separate measurements of the shear modulus taken from each wire sample; a total of 10 measurements for each type of wire. Only five measurements were taken on the 0.0762-mm 304SS wire.

TABLE I. Wire Diameter

Wire Type	Reported Diameter (mm)	Measured Diameter (mm)
MP35N	0.102	0.1011 ± 0.00120
MP35N	0.127	0.1240 ± 0.00122
MP35N	0.152	0.1557 ± 0.00120
MP35N	0.178	0.1755 ± 0.00185
MP35N	0.203	0.2022 ± 0.00189
MP35N	0.229	0.2266 ± 0.00789
304SS	0.076	0.0785 ± 0.00052
304SS	0.127	0.1308 ± 0.00104
304SS	0.178	0.1803 ± 0.00500
304SS	0.203	0.2047 ± 0.00168
304SS	0.229	0.2273 ± 0.00283

TABLE II. Young's Modulus

Wire Type	Diameter (mm)	Young's Modulus (Reported Wire Diameter) ($\times 10^{11}$ Pa)	Young's Modulus (Measured Wire Diameter) ($\times 10^{11}$ Pa)
MP35N	0.102	1.70	1.72 ± 0.0097
MP35N	0.127	1.69	1.78 ± 0.0303
MP35N	0.152	1.81	1.74 ± 0.0115
MP35N	0.178	1.73	1.77 ± 0.0303
MP35N	0.203	1.70	1.72 ± 0.0213
MP35N	0.229	1.82	1.85 ± 0.0299
304SS	0.076	1.73	1.63 ± 0.0158
304SS	0.127	1.73	1.62 ± 0.0130
304SS	0.178	1.65	1.61 ± 0.0212
304SS	0.203	1.61	1.58 ± 0.0112
304SS	0.229	1.60	1.61 ± 0.0083

RESULTS

Wire Diameter

Table I lists the measured wire diameters for both 304SS and MP35N.

As a general rule the MP35N diameter was smaller and the 304SS was larger than the reported values, but the differences were small. The largest difference (3.0%) was observed with 0.127-mm 304SS wire. The relatively large standard deviation for the 0.229-mm diameter MP35N was caused by measurement problems due to a nondistinct diffraction pattern.

Young's Modulus

Table II, contains the measured Young's modulus values for both the MP35N and 304SS wires. *E* was calculated with the use of both the experimentally determined wire diameter (Column 4) and the diameter value provided by Fort Wayne Metals (Column 3). Note that the difference is small.

E for MP35N ranged from 1.72×10^{11} Pa to 1.85×10^{11} Pa, with a mean value of 1.76×10^{11} Pa. The 0.229-mm

TABLE III. Shear Modulus and Poisson's Ratio

Wire Type	Diameter (mm)	Shear Modulus (Reported Wire Diameter) ($\times 10^{10}$ Pa)	Shear Modulus (Measured Wire Diameter) ($\times 10^{10}$ Pa)	Poisson's Ratio
MP35N	0.102	6.68	6.84 ± 0.106	0.26
MP35N	0.127	7.01	7.71 ± 0.073	0.15
MP35N	0.152	7.14	6.57 ± 0.046	0.32
MP35N	0.178	7.45	7.85 ± 0.061	0.13
MP35N	0.203	6.83	6.98 ± 0.058	0.23
MP35N	0.229	4.28	4.44 ± 0.071	NA
304SS	0.076	7.19	6.35 ± 0.202	0.36
304SS	0.127	7.05	6.23 ± 0.098	0.39
304SS	0.178	6.89	6.56 ± 0.103	0.26
304SS	0.203	6.81	6.57 ± 0.040	0.23
304SS	0.229	6.39	6.53 ± 0.034	0.23

value had the highest measured value. All values are significantly less than the published value of 2.35×10^{11} Pa.[2]

For 304SS wire, the experimentally determined Young's modulus ranged from 1.58×10^{11} Pa to 1.63×10^{11} Pa with a mean value of 1.61×10^{11} Pa. *E* found from these experiments were all significantly less than the published Young's modulus of 304SS of 1.93×10^{11} Pa.[3]

Shear Modulus

The shear modulus was calculated with the use of both the wire diameter values provided by the supplier and the experimentally determined diameters Table III.

For MP35N wire, shear modulus ranged from 4.44×10^{10} Pa to 7.85×10^{10} Pa. The 0.229-mm wire had a significantly lower value than all other wire because of measurement errors. If this value is ignored, the mean value of *G* for MP35N was found to be 7.19×10^{10} Pa.

The shear modulus for 304SS wire ranged from 6.23×10^{10} Pa to 6.57×10^{10} Pa, with a mean value of 6.45×10^{10} Pa. These values are less than the published values of 7.5×10^{10} Pa to 8.0×10^{10} Pa.[3,9]

Poisson's ratio of each wire and each material was calculated from the average *E* and *G* data reported here.[9] Poisson's ratio of MP35N ranged from 0.13 to 0.32. For 304SS wire the value ranged from 0.23 to 0.39. If the average values of *E* and *G* are used to calculate ν, the values for MP35N and 304SS are 0.22 and 0.25, respectively.

DISCUSSION OF RESULTS

Initial attempts to measure wire diameter with a micrometer proved futile because of the measuring accuracy—micrometers simply were not sensitive enough. The laser-diffraction technique, proved to be very accurate and produced results that showed the wire was very close to reported diameter. The technique was reproducible and had a standard deviation of approximately 1%. The basic premise of measuring wire diameter with a laser is that the diameter of the wire is of the same order of magnitude as the wavelength of the laser. If the two are close, a very distinct diffraction pattern emerges. If the two differ significantly, the diffraction pattern becomes diffuse and it is difficult to measure to the center of the fringe minima. The diameter of the 0.229-mm wire was sufficiently large so that locating the center of the minima was difficult. This was especially true for the MP35N wire and can be seen in the values of *E* and *G* found in Tables II and III.

Young's modulus was measured in much the same way as in a standard tensile test, except the equipment used here was extremely accurate. The test techniques developed here verified the results from the original tensile testing performed on the wire. The average value of 176 GPa correlated well with *E* of 169 GPa measured on a standard tensile testing machine. It also confirmed that *E* was significantly less than the reported value of 235 GPa.[2] Based on the numbers generated with this technique, *E* for MP35N and 304SS are 26.5% and 16.6% below values found in the literature. It is also significant to note that *E* for both the MP35N and the 304SS did not change significantly from one wire diameter to another. The exception was the 0.229-mm diameter MP35N wire (because of the inaccuracies in measuring wire diameter reported above).

Testing to determine Young's modulus is generally performed on parts 7 mm in diameter or larger. That the largest diameter wire showed the largest *E* value may be an indication that size of the test sample does play a role in the determined value of *E*. At what point sample size becomes a factor is not known. However, it is unlikely that a distinct break point in size exists, above which standard *E* values can be used and below which *E* must be determined independently.

Shear modulus was measured with a very novel approach: a torsion pendulum. By suspending the pendulum from the wire under test and then rotating the pendulum, the shear modulus was directly measured from the periodicity of the pendulum. With the exception of the 0.229-mm MP35N wire, *G* was consistent across wire diameters and within a given material. The nondistinct diffraction pattern for the 0.229-mm MP35N samples resulted in large errors in wire diameter and therefore *G* with a determined value of 44 GPa. The error comes about because *G* is inversely related to the radius of the wire raised to the fourth power, [Eq. (23)]. Shear modulus values determined here differ from reported values[2,3] by 11% and 14%, respectively.

Poisson's ratio is a measure of the transverse strain to axial strain in a specimen under uniaxial tensile load, and the best data usually come from tests performed on single crystals. For MP35N and 304SS wire, calculation of Poisson's ratio should be considered an exercise in mathematics because the calculation is based on the assumption that the wire under test is homogeneous and isotropic. It is not. An analysis of the metallurgy of MP35N provides a good example of why.[2]

In the annealed condition, MP35N has a face-centered-cubic (FCC) structure. It is hardened by transforming the FCC matrix to a hexagonal-close-packed (HCP) phase. The only way to make this phase transformation is by mechanical deformation (cold drawing, for example) of the metal. The cold-drawing process causes very small, thin plates of HCP to form inside the FCC matrix. The number of HCP plates that form is directly related to the amount of cold working; greater amounts of cold drawing result in more of these HCP plates. The wire typically is ordered with a 40–80% cold-worked surface so large numbers of platelets are present, which may or may not be homogeneously distributed throughout the wire. Because of the cold-drawing process, the wire will also have a nonhomogeneous grain structure with a preferred orientation. That is, the individual metal grains will become elongated along the long axis of the wire. This results in the wire having one set of mechanical properties in the longitudinal direction and a second set of properties in the transverse direction—anisotropy.

No metallography was performed on the wire, and no attempts were made to identify the exact reason for the differences in *E* and *G* reported here versus values in the published literature. The differences are believed to be due to anisotropy, and anisotropy makes determination of *E* and *G* suspect. But consider that all materials are anisotropic:[6]

> Further, even a single-phase metal will usually exhibit chemical segregation, and therefore the properties will not be identical from point to point. Metals are made up of an aggregate of crystal grains having different properties in different crystallographic directions. The reason why the equations of strength of materials describe the behavior of real metals is that, in general, the crystal grains are so small that, for a specimen of any macroscopic volume, the materials are statistically homogeneous and isotropic.

The important point is that these wires do not have any significant macroscopic volume. Because this wire is extremely fine, highly cold drawn, and in a geometrical configuration that does not resemble the dumbell-shaped samples used to determine typical elastic properties, published values of *E* and *G* simply do not apply to this wire. But *E* and *G* must be known in order to perform fatigue testing,[5] finite element analysis (FEA),[10,11] and many other calculations. Based on the information in this report, the data from those calculations must be carefully scrutinized.

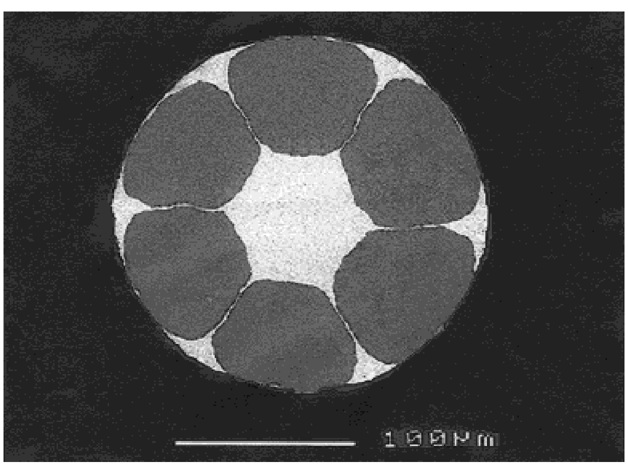

Figure 1. DBS wire. This sample consists of wedges made of solid MP35N (darker color) with silver (lighter color) used to braze the MP35N together and to reduce the electrical resistance of the wire.

TABLE IV. Elastic Properties

		Published	Measured
MP35N	*E* (GPa)	235	176
	G (GPa)	80.0	71.9
	ν	0.46	0.22
304SS	*E* (GPa)	193	161
	G (GPa)	75.0	64.5
	ν	0.29	0.25

It is believed that *E*, *G*, and *ν* should be determined for the particular wire being used in a given application. Although this is an imperfect solution (because of anisotropy), it will provide values that are more representative of the actual physical properties of the wire.

The future of the cardiovascular device industry lies with two new configurations of fine wire, DFT (drawn filled tube) and DBS (drawn braised silver). Figure 1 shows a scanning electron micrograph of DBS wire. There are individual pie-shaped wedges made up of MP35N, a hexagonal-shaped silver core, and thin coatings of silver between the wedges and on the outside surface of the wire (light grey color). The obvious question concerns which mechanical properties to use for this configuration. The values reported here will not be applicable to DBS wire.

CONCLUSION

Three unique mechanical tests were developed and used to test very fine wire used in the implantable device industry. The modulus of elasticity (Young's modulus) and the shear modulus of MP35N and 304SS wire were successfully measured and found to be significantly less than the published values (Table IV). Likewise, the experimentally determined shear moduli of both wire materials were less than published value. The Poisson's ratios calculated from these data, although somewhat variable between different thicknesses of wire, are reasonable for the MP35N and 304SS alloys.

REFERENCES

1. Ratner BD, Hoffman AS, Schoen FJ, Lemons JE. Biomaterials science: An introduction to materials in medicine. Orlando, FL: Academic Press; 1996.
2. Multiphase MP35N Alloy technical data. Latrobe Steel Company, Latrobe, PA; 1980.
3. Metals handbook (9th Ed.). Metals Park, OH: American Society for Metals; 1980. vol. 3.
4. Bolze RE, Tuve GL. In: CRC handbook of tables for applied engineering science. Boca Raton, FL: CRC Press; 1973.

5. Altman PA, Meagher JM, Walsh DW, Hoffman DA. Rotary bending fatigue of coils and wires used in cardiac lead design. J Biomed Mater Res (Appl Biomater) 1998;43:21–37.
6. Dieter GE. Mechanical metallurgy (2nd Ed.). New York: McGraw-Hill; 1976.
7. Lipson SG, Lipson H, Tannhauser DS. Optical physics. Cambridge, England: Cambridge University Press; 1995.
8. Landau LD, Liftshitz EM. Theory of elasticity. New York: Pergamon; 1970.
9. Gere JM, Timoshenko SP. Mechanics of materials. PWS Publishing Company; 1990.
10. Zhao Y, McIntyre P, McMahon C, Laramie H, Cobain K, Miller J. 3-D nonlinear finite element analysis simulation of bellmouth flexural test for pacing lead body. In: Proc ICCMB-11; 2000. pp 323–324.
11. Zhao Y, McMahon C, McCarty J, Laramie H, Laske T, Miller J, Schaenzer D. Finite element analysis modeling of the FDA-required composite lead distal 400 million cycle fatigue test. In: Proc. ICCMB-11; 2000. pp 325–326.