BENDING, TORSIONAL AND EXTENDING ACTIVE CATHETER ASSEMBLED USING ELECTROPLATING

Yoichi Haga*, Masayoshi Esashi**, Shigeo Maeda***
*Faculty of Engineering, Tohoku University
**New Industry Creation Hatchery Center, Tohoku University
***Mitsubishi Cable Industries

ABSTRACT

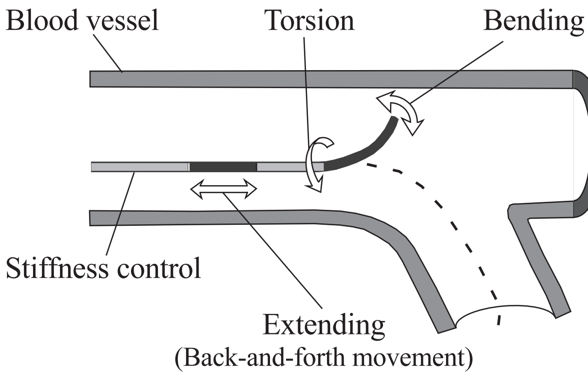
This paper reports a new batch fabrication method of active catheters which have bending, torsional and extending functions for medical applications. The active catheter consists of shape memory alloy (SMA) coil for actuator and a stainless steel liner coil. The SMA coil and the liner coil are connected using nickel electroplating and acrylic resin electrodeposition. This novel method makes low cost assembly and small diameter (ϕ1.4mm) possible. New fabrication method of small diameter and thin wall tubular structure which is suitable for active catheters was developed. The tubular structure consists of stainless steel spring coil, evaporated parylene membrane and dip coated biocompatible polyurethane.

INTRODUCTION

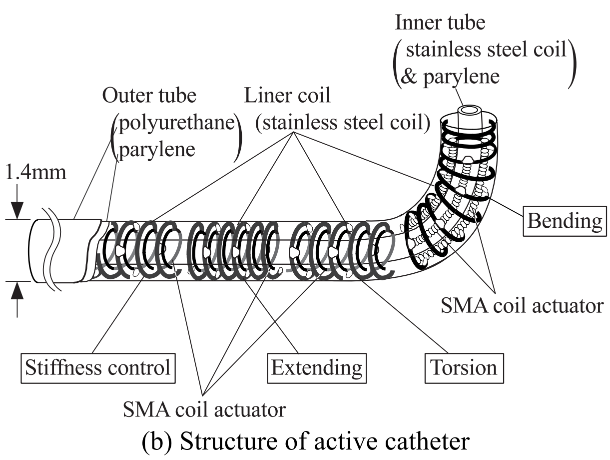
Catheters are used for minimal invasive diagnosis and therapy in blood vessel. Active catheters have been developed for controllable steering. The catheter is controlled from outside the body and moves like a snake utilizing distributed shape memory alloy (SMA) coil actuators [1, 2]. As shown in Fig.1(a), bending, torsional, extending and stiffness control functions make steering of the catheter much easier. The structure to achieve these functions as an active catheter and an active guide wire is shown in Fig.1(b). The active catheter has a working channel that is used for injection or suction of fluids or insertion of micro tools, while the active guide wire doesn't have any working channel but the outer diameter is much smaller than the active catheter.
Firstly, mechanisms for each functions will be described. Next, new assembly method of the active catheter will be described. Finally, fabrication of an outer tube which has suitable mechanical property for the active catheter will be described.

BENDING MECHANISM

Structure of the bending mechanism is shown in Fig.2(a). Three SMA coil actuators are fixed between a stainless steel liner coil and an inner tube. When the SMA coil is heated above a certain transition temperature by an electric current, the SMA coil contracts. Many joints are serially connected and each joint can bend in 6 directions. As shown in an equivalent circuit depicted in Fig.2(b) (one of three SMA coils is shown for simplicity), each joint is individually controlled by using the liner coil as a common ground. For this purpose, mechanical connections and electrical connections between the SMA coil and the liner coil are alternately arranged as shown in Fig.2(c).
In this fabrication, insulator is coated on the liner coil and removed locally using YAG laser for making electrical connections. An electrically conductive adhesive is used in this case, but electroplated metal can be used instead of the adhesive as shown later.
The photograph of the fabricated bending mechanism of which outer diameter is 1.4mm is shown in Fig.2(d). Because the heat transfer from the SMA coil is prevented



(a) Functions of active catheter



(b) Structure of active catheter

Figure 1: Functions and structure of active catheter

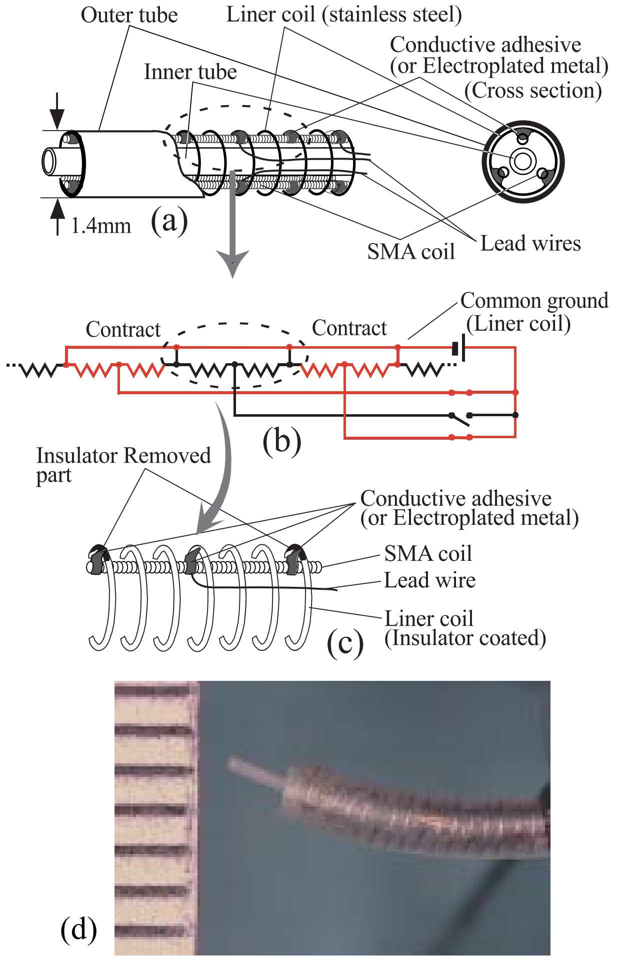


Figure 2: Multi joint bending mechanism

by an air gap between the SMA coil and the liner coil in this structure, this active catheter has a benefit of tolerable surface temperature on the outer tube to be used in human body. Our experiment showed surface temperature was below 41°C when bending mechanism was actuated by the current of 80mA in 38°C water. The diameter without the outer tube is 1.3mm and other mechanisms are designed same diameter size for conformity.

TORSIONAL, EXTENDING AND STIFFNESS CONTROL MECHANISMS

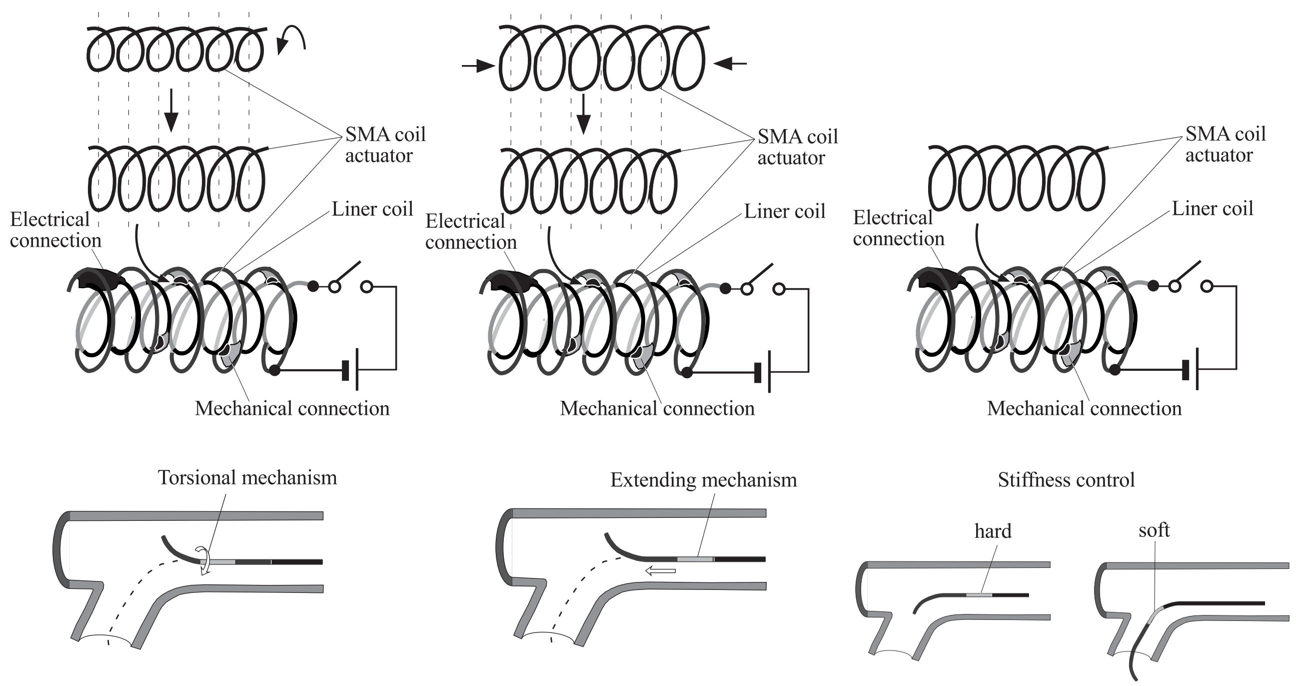
Torsional mechanism

For steering the catheter at branches of blood vessel, “J” shaped tip of catheter or guide wire is torsionally rotated from the outside conventionally. However, the torque cannot be well transmitted controllably when a blood vessel has a loop or complex configuration (poor torquability). This problem can be solved by installing a torsional mechanism in the catheter or the guide wire.

The structure of the torsional mechanism is shown in Fig.3(a). This mechanism consists of a liner coil and a twisted SMA coil fixed coaxially inside the liner coil. The liner coil plays a role of a lead wire. When the SMA coil is heated above a certain transition temperature by electric current, the SMA coil is untwisted. Inversely, the liner coil twists (turns back) the catheter when electric current is turned off.

Extending and stiffness control mechanisms

For moving the catheter or the guide wire forward, they are pushed from outside conventionally. When a blood vessel has a loop or complex configuration, the forward



(a) Torsional mechanism (b) Extending mechanism (c) Stiffness control mechanism

FIgure 3 Structures and principles of torsional, extending, and stiffness control mechanisms

movement is inaccurate because of the flexion of the catheter or the guide wire body (poor pushability). On the contrary, retracting the catheter or the guide wire is relatively accurate. For positioning the tip to the aimed lesion, the tip have to be moved forward beyond the lesion once and retracted. The risk of perforation increases if the body of the catheter or the guide wire is hard and on the contrary, pushability and torquability is poor when they are soft.
Fine positioning of the tip is realized when an extending and retracting mechanism is mounted near the tip of the catheter or the guide wire as shown in Fig. 1. Structure of the extending mechanism is shown in Fig.3(b). This mechanism consists of a liner coil and a compressed SMA coil coaxially fixed inside the liner coil. The liner coil plays a role of a lead wire and a bias spring. When the SMA coil is heated above a certain transition temperature by an electric current, the SMA coil extends. Inversely, the liner coil restore the catheter shape when electric current is turned off. A 1.4mm outer diameter extending mechanism was fabricated and was confirmed its motion.
Stiffness control mechanism also makes steering of a catheter or a guide wire easy. As shown in Fig.3(c), the body of the catheter or the guide wire can be hard when the mechanism passes a straight portion, while the body can be soft when the mechanism passes a curved portion. The stiffness control mechanism consists of a liner coil and a natural state (not deformed) SMA coil coaxially fixed inside the liner coil. The SMA coil doesn't deform but hardens when electric current is applied.

ASSEMBLY USING ELECTROPLATING

Required conditions for the assembly of the active catheter

Following conditions are required to make all mechanisms mentioned above.

(a) making mechanical connections between the SMA coil and the liner coil at aimed positions.
(b) keeping process temperature below 40°C to avoid SMA deformation.
(c) making electrical connections between SMA coils and lead wires, and between a SMA coil and a liner coil.
(d) short time and low cost assembly.

Active catheters were assembled using electrically conductive and non-conductive adhesives [1]. However, it is not easy to make many small connections between a SMA coil and a liner coil. UV curable resins or laser assisted CVD (chemical vapor deposition) can be also used [2] but it takes long time because many connections have to be formed individually.
To solve these problems, following new assembly method using nickel electroplating and acrylic resin electrodeposition was developed.

Making mechanical connections between SMA coil and liner coil

Firstly, insulator was coated on the SMA coil using elec-

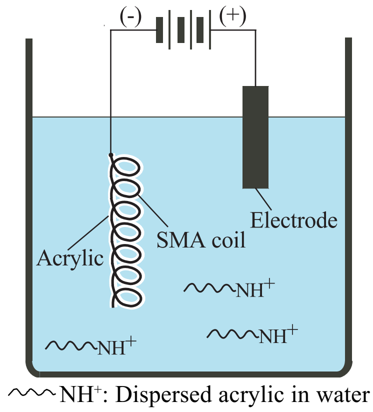


Figure 4: Setup for insulator coating on SMA coil.

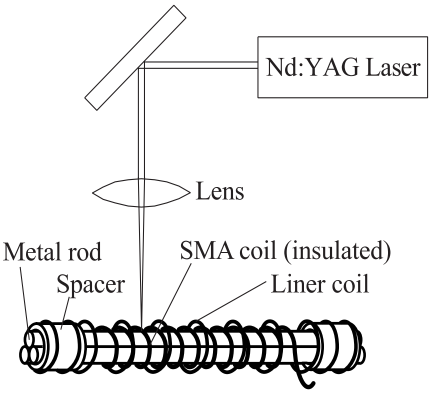
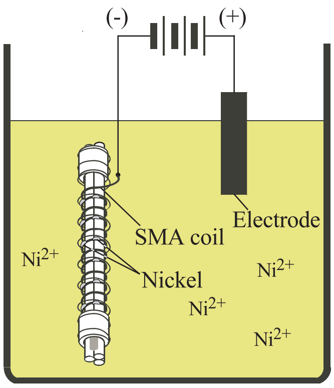
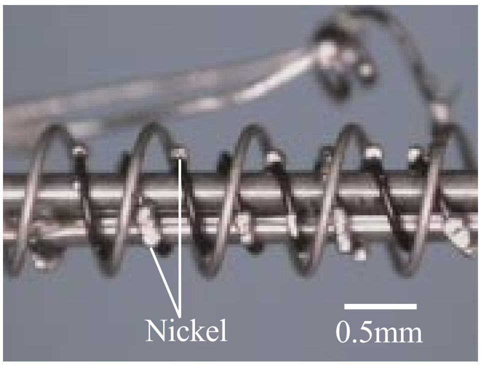


Figure 5: Removing of insulator on SMA coil by YAG laser



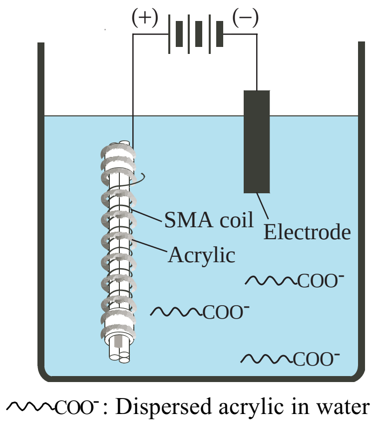
(a) setup



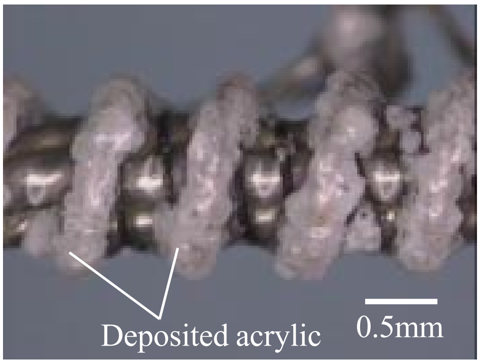
(b) deposited nickel

Figure 6: Nickel electroplating on SMA coil.

trodeposition of acrylic resin (Shimizu Co., LTD., CMEX) as shown in Fig.4. This process can be replaced by parylene evaporation. Next, insulator was locally removed using YAG laser at many portions as shown in Fig.5. Next, nickel is electroplated simultaneously at the insulator removed portions as shown in Fig.6. Natural oxide layer on the SMA is removed using diluted fluoric acid before the electroplating. The structure after the nickel electroplating is shown in Fig.6(b). The rods inside the SMA coil is a jig which is removed later. Next, thick acrylic resin (Shimizu Co., LTD., UA-51) is electrodeposited as shown in Fig.7. The acrylic resin is dried by



(a) setup



(b) deposited acrylic

Figure 7: Acrylic electrodeposition on liner coil

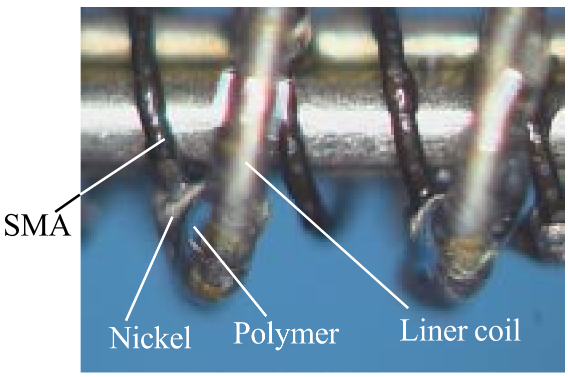


Figure 8: Mechanical connections between SMA coil and liner coil (After drying and UV cure)

exposing it to vacuum (0.16~0.18 Torr) for one hour and cured by irradiation of UV light (1200mJ/cm^2). Deposited acrylic resin gets clear and smooth as shown in Fig.8 after the dehydration. Many connections between the deposited nickel on the SMA coil and the liner coil are formed simultaneously in this process.

Making electrical connections using Ni electroplating

As described before, electrical connections between a liner coil and a SMA coil are necessary for utilizing a liner coil as a part of the electric circuit to apply current to the SMA coil. As shown in Fig.9, the electric connections are formed by second local removing of the insulator on the SMA coil and the liner coil using a YAG laser and by following second nickel electroplating. As shown in Fig.10, lead wires are electrically connected to the SMA coil by setting lead wires on the SMA and by following nickel electroplating.

Active catheters fabricated using electroplating

A torsional mechanism fabricated using nickel electroplating and acrylic electrodeposition is shown in Fig.11. Outer diameter of the mechanism is 1.3mm without outer tube and length is 7mm. The electrical connection is formed at the tip to use a liner coil as a part of electric circuit. Torsional rotation of 70 degree was obtained by the current of 80mA as shown in Fig.12.
The bending mechanism was also assembled using the nickel electroplating and the acrylic electrodeposition as shown in Fig.13.

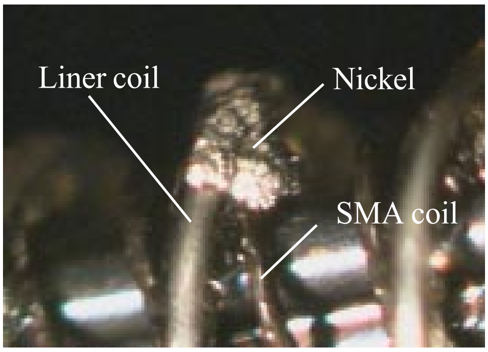


Figure 9: Electrical connection between SMA coil and liner coil

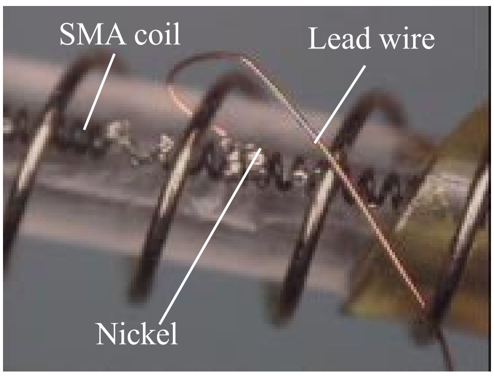
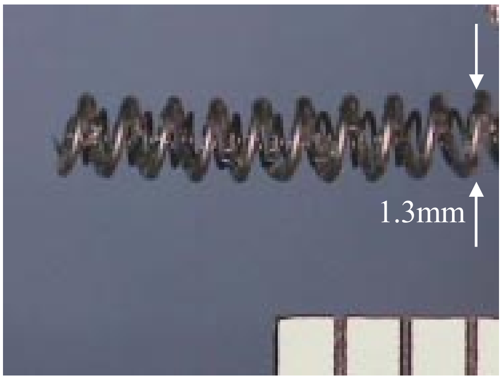
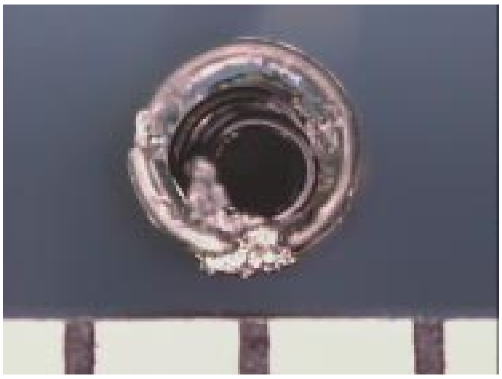


Figure 10: Electrical connection between lead wire and SMA coil



(a) side view



(b) front view

Figure 11: Torsional mechanism

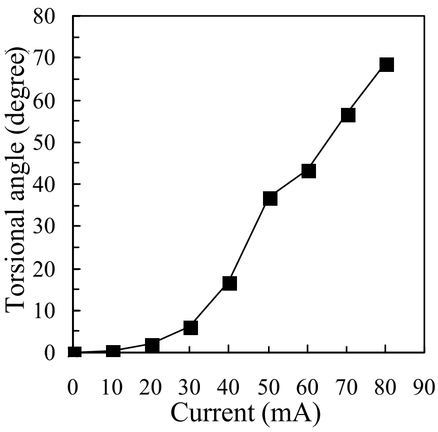


Figure 12: Characteristics of torsional mechanism

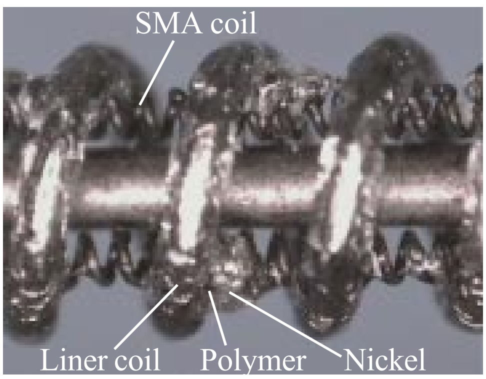
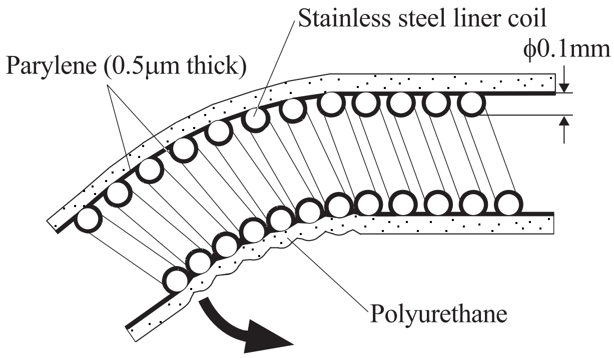


Figure 13: Assembly of the bending mechanism using electroplating

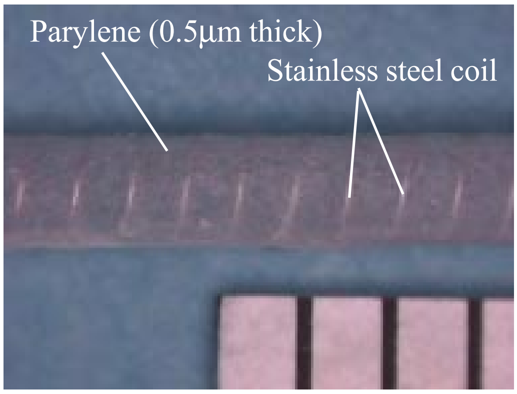
THIN-WALLED AND ANTICOAGULANT OUTER TUBE

The active catheter has an outer tube that covers the inside mechanisms for waterproof and electrical insulation. This makes the active catheter usable in blood or other environment. Thick-walled or hard outer tube prevents the motion of active catheters. Then, thin-walled silicone rubber tube (outer diameter =1.4mm, wall thickness =0.1mm) was used as an outer tube of active catheters before [1]. But thin-walled silicone rubber tube easily collapses. Thin-walled tube with the supporting liner coil solves these problems.

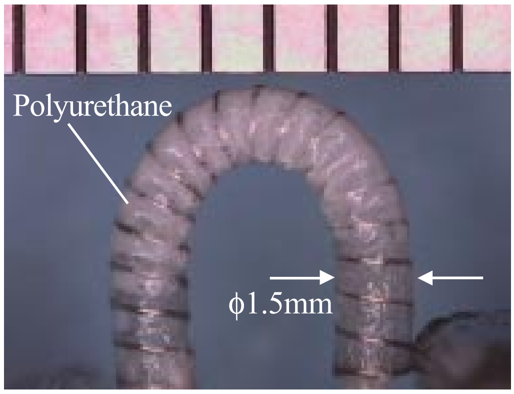
For making such tubular structure, liner coil is covered with thin parylene and it is coated with biocompatible



(a) cross section



(b) fabricated parylene tube



(c) after polyurethane dip coating

Figure 14: Thin-walled tube supported by coil spring

polyurethane. The fabricated structure is shown in Fig.14. The fabrication process of the thin-walled and anticoagulant outer tube on the torsional mechanism is shown in Fig.15.
Firstly, a torsional mechanism is covered with a silicone rubber tube (Fig.15(b)) and parylene C (poly-monochloro-para-xylylene) is evaporated for making an inner wall on the liner coil (Fig.15(c)). The silicone rubber tube is removed using silicone rubber etchant (Kanto chemical, KSR-1) (Fig.15(e)). Next, it is dip coated with polyurethane (Dow chemical, Pellethane 2363-80AE) diluted in dimethylformamide (4wt%) (Fig.15(f)). Finally end sealings are removed and an inner tube is inserted (Fig.15(g)).
This process can be also used for making an outer tube of an active guide wire as shown in Figure 16.

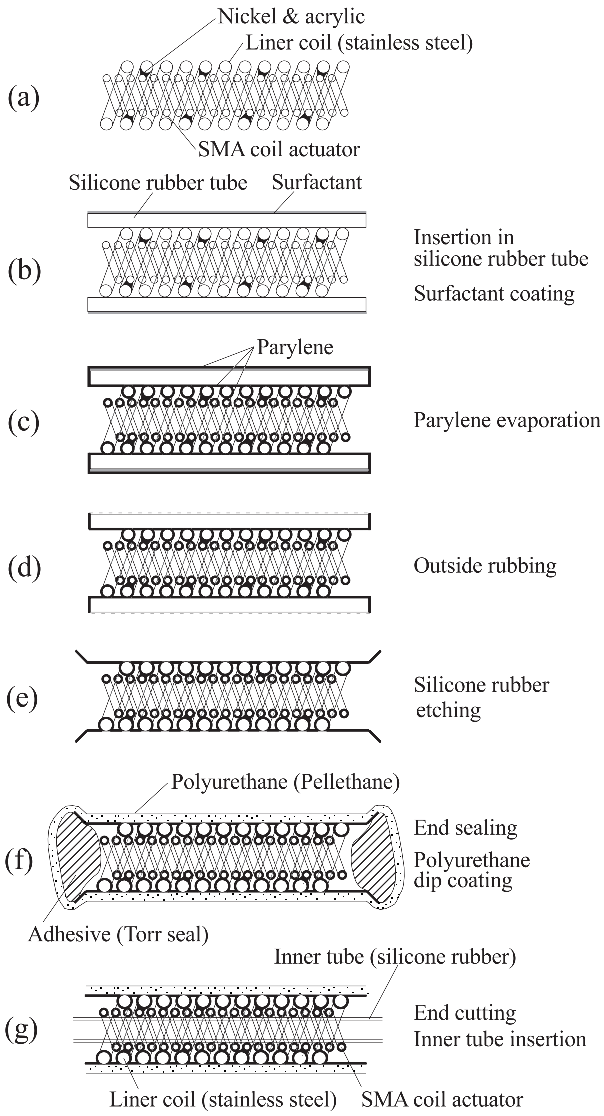


Figure 15: Fabrication of polyurethane outer tube on active mechanism (torsional mechanism is exampled)

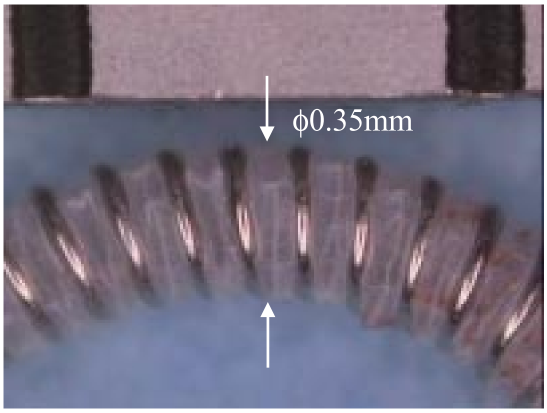


Figure 16: Fabricated 0.35mm outer diameter parylene tube.

CONCLUSION

An active catheter that has bending, torsional, extending, and stiffness control mechanisms was developed using new batch assembly method using nickel electroplating and acrylic electrodeposition. Fabrication method for making an outer tube of active catheters was also developed. These novel method makes low cost and short time assembly to make small diameter active catheters and active guide wires.

ACKNOWLEDGMENTS

This work was partly supported by the Grant-in-Aid for Scientific Research from Ministry of Education, Scientific, Sports, and Culture of Japan (10359001) and the Japan Society for the Promotion of Science (Research for the Future Program : Project No. 96P00802). I wish to thank Shimizu Co., LTD. for providing the electrodeposition acrylic resin. I wish to thank Dow Chemical Company for providing medical-grade polyurethane. Parylene is trademark of ThreeBond Co.,LTD.

REFERENCES

[1] Y.Haga, Y.Tanahashi and M.Esashi, "Small diameter active catheter using shape memory alloy" Proc. MEMS-98, pp. 419-424, Heidelberg, Germany.
[2] G.Lim, K.Park, M.Sugihara, K.Minami, and M.Esashi, "Future of active catheters", Sensors and Actuators, A 56, pp.113-121, 1996.