

The Prevention of Neuroma Formation by Diathermy: An Experimental Study in the Rat Common Peroneal Nerve⁺

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Abstract

Introduction: There have been anecdotal reports of the efficacy of diathermy (electrocoagulation) in the prevention of neuroma formation. However, this has not been investigated in the laboratory. In this experiment involving 40 rats, diathermy was applied to the terminal proximal ends of transected rat common peroneal nerves to evaluate its effect on neuroma formation. **Materials and Methods:** Monopolar and bipolar diathermy set at 45 W, applied for different durations (4 seconds and 10 seconds), were evaluated. Under histological control, the presence of neuroma formation and the diameter of the nerve ends were evaluated at 3 months. The contralateral common peroneal nerve in the same rat served as the control. The dorsal root ganglia of 2 rats in each group were also harvested for histological study. **Results:** The incidence of neuroma formation was 30% in the group which received high-duration monopolar diathermy (10-second application), versus 90% in the control group ($P < 0.05$). The mean diameter of the nerve ends was smaller at 0.51 mm [standard deviation (SD), 0.29] versus 0.85 mm (SD, 0.24) in the control ($P < 0.05$). The incidence of neuroma formation was 30% in the group which received low-duration monopolar diathermy (4-second application), and 83% in the control group ($P < 0.05$). The diameter was 0.43 mm (SD, 0.14) versus 0.85 mm (SD, 0.28) ($P < 0.05$). High-duration bipolar diathermy applied for 10 seconds, showed a neuroma formation of 25% versus 100% in the control group ($P < 0.05$). The diameter of the nerve ends was 0.48 mm (SD, 0.07) versus 0.79 mm (SD, 0.36) in the control group ($P < 0.05$). The incidence of neuroma formation was 60% in the low-duration bipolar group, which received bipolar diathermy application for 4 seconds, and 90% in the control group ($P = 0.25$). The diameter of the nerve ends in the low-duration bipolar group was 0.52 mm (SD, 0.24) versus 0.76 mm (SD, 0.40). The incidence of neuroma formation and the difference in diameter in the low duration-bipolar group were both not statistically significant. **Conclusion:** This study demonstrates the effectiveness of monopolar diathermy in reducing the rate of neuroma formation. For bipolar diathermy, an application of 10 seconds was effective in reducing neuroma formation but an application of 4 seconds was not associated with a significant reduction in neuroma formation.

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Key words: Diathermy, Electrocoagulation, Ganglia, Neuroma

Introduction

Neuroma formation in extremity amputations, particularly finger amputations, can be extremely disabling. There have been many methods advocated for the prevention and management of such amputation neuromas,¹⁻²⁹ but no one method has been shown to be ideal. The most popular and simplest method, peripheral neurectomy, involves the proximal section of the nerve in such a way that the neuroma is situated in a well-vascularised and padded area.¹ Unfortunately, the digit has a paucity of soft tissue,

and digital neuromas may adhere to scar tissue or bone and cause severe pain. Other methods include epineurial ligation, microsurgical funicular closure, silicone capping, transposition, microneural anastomoses, chemicals (phenol, alcohol, steroids, ricin, nitrogen mustard), and radioactivity. The disadvantages of these various methods include poor results,¹² high costs, toxicity, need for microsurgical skill, prolonged surgery, excessive dissection, and additional logistical requirements. Although there has been a plethora of reports on the different methods of preventing or treating

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amputation neuromas, there has been no published journal article in the English language on the use of diathermy. Anecdotal experience in our practice has suggested that the application of diathermy to transected nerve ends in finger amputations were not associated with symptomatic neuromas. In addition, a case report reported the use of thermocautery as a useful method in the prevention of traumatic neuroma of the great auricular nerve during parotid surgery.³⁰ A German paper published in the 1950s briefly reported anecdotal experience on the use of percutaneous electrocoagulation as a method of performing proximal neurectomies for the management of symptomatic amputation stump neuromas.³¹ Hence, the aim of this study was to examine the incidence of neuroma formation following diathermy of scalpel-transected nerve ends of the common peroneal nerve (CPN) in rats.

Materials and Methods

Experimental Animals

Adult male Wistar rats (mean weight, 439 g) were used in the study. Animals were housed in the Singapore General Hospital Experimental Surgery Laboratory and had unlimited access to food and water throughout the duration of the experiments. A total of 40 animals were used; each experimental group consisted of 10 animals, with a total of 4 experimental groups, designated BL, BH, ML and MH.

Procedure

Under ketamine anaesthesia (1 mg to 2 mg subcutaneously), all rats had bilateral CPN scalpel transection, 10 mm distal to the bifurcation of the sciatic nerve following mobilisation of the nerve. This procedure was performed under an operating microscope using micro-instruments. Prior to nerve transaction, 1% lignocaine was infiltrated into the area of the sciatic nerve bifurcation to provide local anaesthesia. A 12-mm segment of the CPN distal to the transaction was then removed to prevent any subsequent reconnection. In all the rats, diathermy was carried out on the transected end of the CPN of 1 side. In each animal, the contralateral CPN served as an un-diathermised control. In group BL, the transected end of the CPN of the treatment side received low-duration bipolar diathermy (4 s). In group BH, the transected treatment nerve end received high-duration bipolar diathermy (10 s). The last 2 groups received monopolar diathermy to the transected ends of the treatment CPN. One group (ML) received low-duration (4 s) application, and another group (MH), high-duration (10 s) application.

Diathermy on the transected end of the CPN was performed by the same investigator. The electrical diathermy unit was calibrated before the start of the study to ensure that all the nerve ends received the same amount of energy

(45 W). The duration of diathermy current was also controlled via a timer switch mechanism incorporated into the external circuit of the machine to ensure that all the nerves received exactly the prescribed duration of treatment. For monopolar diathermy, the transected end of the CPN was held up firmly with fine microforceps, away from surrounding tissues, and the monopolar diathermy pencil was then applied to the metallic part of the forceps. On activation of the monopolar diathermy, the current was delivered for either 4 or 10 seconds, depending on the group. Charring of the distal 5 mm to 10 mm of the nerve was noted. The treated nerve end was then replaced into its bed and layered closure of the gluteus muscle and skin with absorbable sutures performed. On the contralateral control side, after mobilisation and nerve transaction, the nerve end was left in its bed and the wound closed in layers. For bipolar diathermy, the transected nerve end was held up with fine microforceps and the bipolar diathermy applied just proximal to the forceps.

For 3 months, all the rats were allowed to run free in cages. Three months post-transaction, the CPN on both sides were carefully dissected out and the distal nerve end or neuroma excised in all the animals. The tissues were then sent for histological examination for neuroma formation using haematoxylin & eosin stain, myelin blue stain and Bielschowsky's silver stain. In addition, the histological diameter of the nerve or neuroma was measured under microscopy.

In addition to the harvesting of the CPN, 2 rats from each group were randomly chosen to be euthanised for harvesting of the dorsal root ganglions of both the treatment and contralateral control CPN. This was achieved via a laminectomy. The harvested dorsal root ganglions (Fig. 1) were then sent for histological examination. Histological examination consisted of transverse sectioning of the centre of the ganglions and staining with haematoxylin & eosin stain. The total number of ganglion cells in a representative transverse section of each harvested dorsal root ganglion was also counted using SigmaScan Pro 5.0.0.1 developed by SPSS.

Statistical analysis was performed on SPSS 10.0.5 using McNemar's Chi-square test for dichotomous data (incidence of neuroma formation) and Wilcoxon signed rank test for continuous data. A statistically significant result was defined as $P < 0.05$.

Results

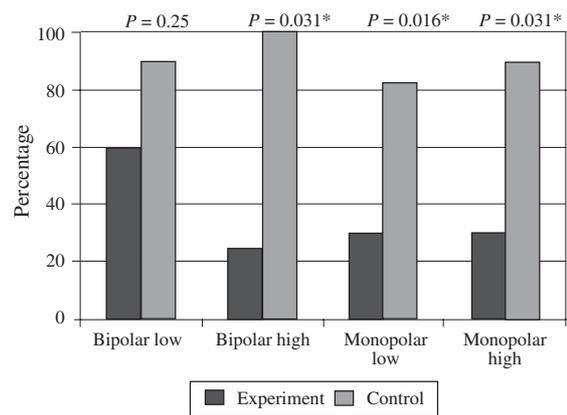
No abnormal neuroanatomy with regard to the sciatic nerve and the CPN of the rats were noted during the dissection. No motor deficit or ulcer was noted in the hind limbs of all the rats during the course of the experiment. There was 1 case of haematoma formation in the wound,



Fig. 1. Harvested dorsal root ganglion with its rootlets to the right of the bulbous ganglion and spinal nerve to the left.

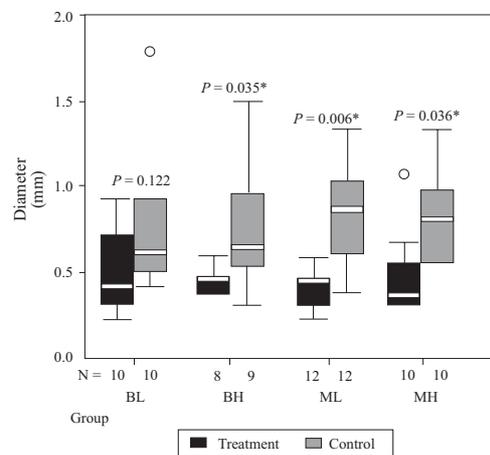
which was treated by early drainage. No other complications were noted. None of the transected nerve ends were found to have reconnected spontaneously to surrounding nerves or their distal segments.

Based on histological examination of the nerve ends at 3 months, the 10 rats which received low-duration bipolar diathermy (BL) had a neuroma formation of 60%. The neuroma formation in the control nerve in this group of rats was 90%. This difference was not statistically significant ($P = 0.25$). The mean histological diameter of the nerve ends or neuroma as measured under light microscopy in the treatment nerve was 0.52 mm (SD, 0.24), compared to 0.76 mm (SD, 0.40) in the control nerve ends or neuroma. The difference was again not statistically significant in this group. In the group of rats which received high-duration bipolar diathermy (BH), neuroma formation was 25% in the treatment nerve versus 100% in the control nerve. The mean diameter of the treatment nerve ends in the treatment group and the control group was 0.48 mm (SD, 0.07) and 0.79 mm (SD, 0.36), respectively. Both results were statistically significant ($P < 0.05$). In the group, where the treatment nerve ends were subjected to low-duration monopolar diathermy (ML), neuroma formation was 30% in the treatment nerve, and 83% in the control nerve. The difference was statistically significant ($P < 0.05$). The mean diameter of the treatment nerve ends was 0.43 mm (SD, 0.14) versus 0.85 mm (SD, 0.28) on the control nerve. The



* P value computed with McNemar's test where $P < 0.05$ is considered significant.

Fig. 2. Neuroma formation between the 4 groups.



* P value computed using Wilcoxon signed rank test where $P < 0.05$ is considered significant.

Fig. 3. Chart comparing the diameters of the neuromas or nerve ends in the 4 groups.

difference in diameter was also statistically significant in this group ($P < 0.05$). In the last group of rats which received high-duration monopolar diathermy (MH) on their treatment side, neuroma formation in the transected nerve ends was 30% and 90% on the control side ($P < 0.05$). The mean diameter was 0.51 mm (SD, 0.29) on the treatment side and 0.85 mm (SD, 0.24) on the control side ($P < 0.05$). These results are summarised in Table 1, Figures 2 and 3.

Table 1. Neuroma Formation at 3 Months Post-transection

	Low-duration bipolar (BL) $P = 0.25$		High-duration bipolar (BH) $P = 0.031^*$		Low-duration monopolar (ML) $P = 0.016^*$		High-duration monopolar (MH) $P = 0.031^*$	
	Treatment	Control	Treatment	Control	Treatment	Control	Treatment	Control
Neuroma	60%	90%	25%	100%	30%	83%	30%	90%

BL: bipolar low; BH: bipolar high; ML: monopolar low; MH: monopolar high

* P value computed using McNemar's test where $P < 0.05$ is considered significant.

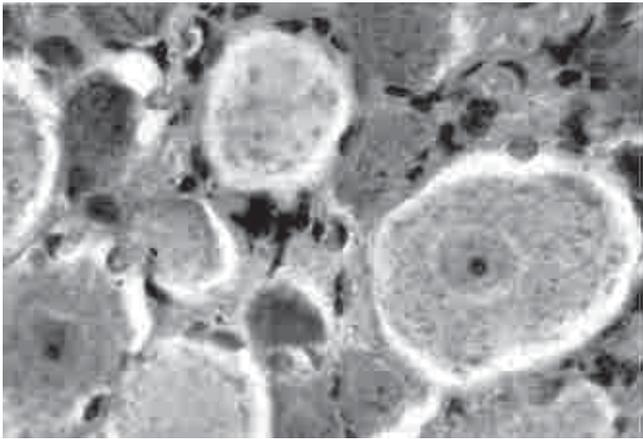


Fig. 4. Type L cell under high magnification with oil immersion 100x, HE stain – light, round cell with round nucleus and prominent nucleolus. Predominant cell type in dorsal root ganglia of common peroneal nerve treated with diathermy.

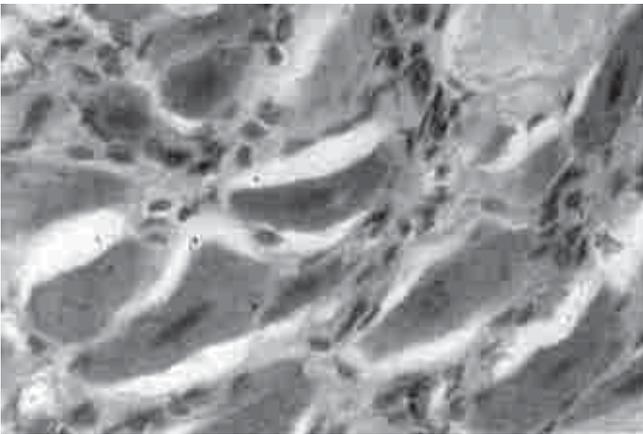


Fig. 5. Type D cell under high magnification with oil immersion 100x, haematoxylin & eosin stain – dark, small cell with elongated nucleus. Nucleolus not prominent. Predominant cell type in control dorsal root ganglia.

Histological examination of the treatment and control dorsal root ganglions of the 8 sacrificed rats showed that the cumulative number of dorsal root ganglion cells in the representative 8 treatment and 8 control dorsal root ganglia histological slides were 1140 and 982, respectively. Two distinct morphological ganglion cell types, large light cells (Type L) and small dark cells (Type D), were noted.³² Type L cells are large and round, with basophilic cytoplasm, large nucleus, and prominent nucleolus (Fig. 4). Type D cells are smaller, spindle-shaped cells, with an elongated nucleus and a nucleolus that is not prominent (Fig. 5). The dorsal root ganglia of the treated CPN consistently showed a significantly larger proportion of Type L cells (70.96%) compared to the dorsal root ganglia of the contralateral control CPN (2.55%) ($P < 0.00005$) (Figs. 6 and 7). The proportion of Type L cells in the dorsal root ganglia of the monopolar treated CPN was significantly larger (89.2%) compared to the bipolar treated CPN (49.1%) ($P < 0.00005$).

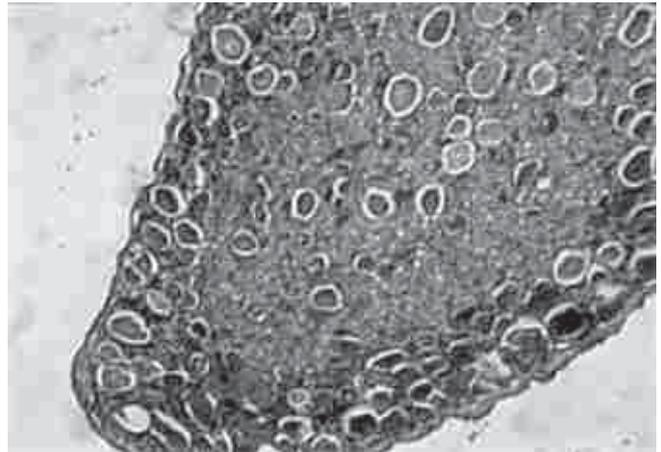


Fig. 6. Transverse histological section (magnification 10x, HE) through centre of treatment dorsal root ganglia showing predominance of Type L cells.

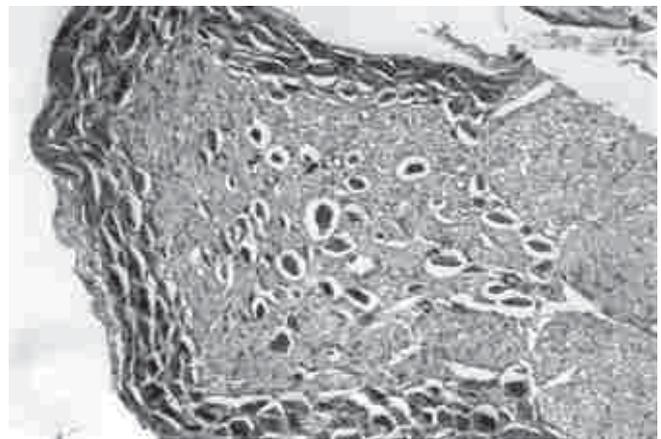


Fig. 7. Transverse histological section (magnification 10x, HE) through centre of control dorsal root ganglia showing paucity of Type L cells.

Discussion

The prevention of neuroma formation using diathermy has not been previously described in the English literature. Except for anecdotal reports, we were unable to find any other published articles in English language journals. We used the following key words “Electrosurgery”, “Electrocautery”, “Thermocautery”, “Electrocoagulation” and “Diathermy”, in five separate searches in combination with the keyword “Neuroma”, using PubMed.

The study was performed to determine if neuroma formation in transected peripheral nerves could be reduced by performing diathermy on the transected nerve ends. The CPN was chosen as it did not lead to significant disabilities after transaction. In sciatic nerve transaction, a huge ulcer was found to develop on the posterior aspect of the hind limb after a few weeks. This resulted in significant disability to the rats and also led to hygiene issues within the rat cages.

A wattage of 45 W was chosen for the diathermy as this was the maximum wattage that could be applied to the

nerve without producing convulsions in the rat when used with monopolar diathermy. A timed duration of 10 seconds was chosen as high duration; as beyond that timing, no perceptible charring of the nerve was seen or heard anymore. A timed duration of 4 seconds was chosen as low duration as 4 seconds is the period when most of the charring would have occurred.

Heat production during diathermy use is proportional to the current strength, duration of current flow, and the resistance of the conductor. Damage to anatomical structures is a consequence of the heat set free when the resistance of a tissue results in the conversion of electrical energy to thermal energy. The greater the resistance of the tissue, the more efficient the conversion of electrical to thermal energy. A low-voltage electrical current as in diathermy will take the path of least resistance. Nerve tissue has the lowest resistance in the body³³ and thus conducts electricity easily, and over a longer distance. Although the heat production is reduced in nerve tissue, damage still occurs as nerve tissue is very susceptible to thermal damage.

At 3 months post-transaction, all the nerve ends were dissected under operating microscope and micro-instruments. Identification of the nerve end was facilitated by the presence of a blue 7-0 ethilon epineural suture which had been inserted at the first operation. This suture was inserted for both the treatment side and the control side. Based on observations, we did not find that the treatment side which received diathermy had more adhesions or scarring than the control side.

Although neuroma formation at the nerve ends could be observed under the operating microscope at 3 months, we chose to base our observations and measurements on histological specimens for greater accuracy and precision. Although gross observations also revealed a reduction of neuroma formation rate in the treatment nerve ends compared to control nerve ends, histological examination was more sensitive in detecting neuroma formation.

A traumatic neuroma is as a non-neoplastic, disorganised proliferation of axons, and accompanying Schwann and perineural cells. Macroscopically, a traumatic neuroma is defined as a firm, demarcated but non-encapsulated bulbous masses arising at the proximal nerve stump. Microscopically, the traumatic neuroma is distinguished by their haphazard arrangement of bundles of regenerating axons ensheathed by Schwann cells.³⁴ This is the criterion used to define neuroma in this study.

Overall, in all the 40 control nerve ends, neuroma formation was present in 90%. Overall, in the 40 treatment nerve ends, neuroma formation was present in 35%. Within the 4 groups, there was a reduction in the rate of neuroma formation in the treatment nerve ends compared to their

own controls. However, these differences were only statistically significant in the groups which received monopolar diathermy and high-duration bipolar diathermy, i.e., the MH, ML and BH groups. Although there was a reduction in neuroma formation in the group which received low-duration bipolar diathermy (BL), this difference was not statistically significant.

Although the study has shown that monopolar diathermy applied for at least 4 seconds, and bipolar diathermy applied for at least 10 seconds, resulted in a reduction in the rate of neuroma formation, the study is unable to come to a significant conclusion as to which of the 3 methods is the most efficacious in reducing or preventing neuroma formation. Statistical analysis did not show any significant difference among the efficacy of the 3 methods.

At this stage, the study is unable to give any conclusive evidence on the cause of the reduced rate of neuroma formation after the performance of diathermy on transected nerve ends. We all know that sharp transaction of a peripheral nerve results in subsequent Wallerian degeneration which may extend to 1 or 2 internodal segments. Following that, regeneration occurs with the formation of neuroma. Israeli investigators have shown that diathermy can cause extensive destruction to Schwann cells, but leaves the myelin and the axons well-preserved.³³ Diathermy results in damage to a longer segment of the nerve compared to sharp transaction. It is possible that the persistence of such a segment of coagulated myelin and axon at the injured nerve end inhibits axonal regeneration following nerve transaction, preventing neuroma formation. This could be contributed by the loss of Schwann cells, which are important for stimulating nerve regeneration.^{35,36}

Another postulate is that due to the high conductivity of the nerve,³⁷ electrical energy is conducted a significant distance up the nerve, especially in the case of monopolar diathermy. If the injury extends too proximally, the cell body will die. The conduction of thermal or electrical energy up the nerve could eventually cause the death of the dorsal root ganglion cell body of the sensory axons and there would be no sensory axonal regeneration and neuroma formation.³⁸ An experiment was performed in which neuroma formation was inhibited in transected nerve ends in rats via the intraneural application of ricin into the transected nerve ends.³⁹ Retrograde transport of the ricin resulted in complete destruction of all the cell bodies in the affected ganglia. Unfortunately, this method is too risky and the amount of collateral damage, too extensive. In addition, the spread of the ricin into the spinal cord could not be excluded. In our study, a computer-assisted counting of the number of ganglion cells in a transverse histological section of the dorsal root ganglia did not appear to show that the number of ganglion cells in the treatment groups

was smaller than that of the control groups. In fact, the number of ganglion cells counted in the treatment ganglia (1104) was higher compared to the control ganglia (982). Thus, death of ganglion cells following diathermy of transected nerve ends is not a likely cause of reduced neuroma formation in our study.

The final postulate is that the thermal damage produces coagulative necrosis and thrombosis of vasa nervorum, resulting in ischaemia and delayed fibrosis of perineural structures, thus sealing the dome of the divided nerve trunk.³⁷

The finding of 2 distinct populations of ganglion cells was interesting. Type L cells are lighter and larger. They have a round cell body, with a large round nucleus with a prominent nucleolus. Type D cells are smaller and darker. They have a spindle-shaped cell body, with an elongated nucleus. Its nucleolus is not prominent. We found a predominance of Type L ganglion cells in treatment ganglia and a predominance of Type D cells in control ganglia. The difference in proportions of Type L cells in treatment and control ganglia were highly significant ($P < 0.00005$). It is apparent that although diathermy does not result in the loss of dorsal root ganglion cells, it appears to induce some morphological changes to the ganglion cells in the dorsal root ganglion. It also appears that monopolar diathermy causes more morphological change compared to bipolar diathermy, as evidenced by the different proportions of Type L cells (89.2% versus 49.1%, $P < 0.00005$). Further experiments would be needed to elucidate the reasons for this morphological change.

Conclusion

In conclusion, monopolar (45 W for 4 s, 10 s) and bipolar diathermy (45 W for 4 s, 10 s) were shown to reduce neuroma formation in transected rat CPNs. However, the reduction was not statistically significant for bipolar diathermy applied for 4 seconds. The aetiology of reduced neuroma formation did not seem to be due to central death of dorsal root ganglion cells. The dorsal root ganglia of diathermised nerve ends showed a significantly larger proportion of Type L cells compared to control dorsal root ganglia. Further studies are being performed to determine the cause. Diathermy could be a useful adjunct in the prevention of neuroma formation and can be performed in conjunction with peripheral neurectomy or soft tissue transposition. The equipment is cheap and widely available, and the procedure is easy and convenient to perform.

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