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# The Insect Fascicle Morphology Research and Bionic Needle Pierced Mechanical Mechanism Analysis[1]

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**Abstract:** In this paper, mosquito and cicadas two kinds of insects fascicle were studied, and observed the fascicle surface morphology and distribution through scanning electron microscopy, discussed the height of the six parameters of sawtooth and analyzed quantitatively, compared the two types of fascicle in micro-structure size, and shape, the experiment results show that there are obviously different among the two mouth fascicle morphological structure. Triangular sawtooth are all clearly visible in the two kinds of insect fascicle, in which the mosquito has the small microstructure, and the cicada has the larger one; microstructure of mosquitoes tilt to the rear part of the fascicle, while the microstructure of cicada is symmetric on bottom corner. Based on non-smooth surface structure of fascicle obvious principles of drag reduction effect, the model of drag reduction bionic syringe is proposed, Designed a bionic drag painless needles, and simulated needle piercing power is also measured. Bionic needle surface microstructure can help reduce the needle to decrease the contact area, form rolling, friction, and thus reduce the resistance to needle piercing. Bionic needle has been proved that its puncture resistance is less than smooth one consequently has significant drag reduction effects.
**Keywords:** Insects fascicle; surface morphology; bionic needles; drag reduction

## 1. INTRODUCTION

Hypodermic that injects the drugs directly into the body through piercing the skin with syringe is a common medical injection method. The pain during injection process is a painful process for common people, which

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is mainly derived from physiological factors, namely traumatic pain because of the stimulation of the injection site soft tissue caused by needles during injection process. Painless injection techniques is the physiological factor for the pain of injection, which achieves pain-free injections through two aspects which decrease or eliminate pain from nerve stimulation and reduce friction between the skin and syringes (QI et al., 2009).

Many research institutes and scholars at home and abroad studied painless injection technique, mainly including micro-needles, which achieve the painless effect through decreasing needles in size to reduce injection pain on the skin nerves (Davis et al., 2005; Griss & Stemme, 2003; Park et al., 2005); using the mechanical device or the ultrasonic or ionization method to inject drugs directly enter human body skin without needle injection (O'Shaughnessy & Paul, 1998; Kersten et al., 2007; Stachowiak & Jeanne, 2007; Ziegler & Andreas, 2007; MacDonald & Canino, 2007), and painless injection bionic needles using the drag reduction mechanism (WANG et al., 2008). Where there are little faults with micro-needles for its small doses of injected drugs and not conducive to absorb (Vandervoort & Ludwig, 2008) , meanwhile its tiny size is also likely to fracture in the body, causes the defects like blood clots complications (Stephanie, 2002). No needle injection needs more auxiliary facilities, with limited drug supply, and manufacturing process is relatively complex, bionic painless needles are bionically designed on the surface of common needles, does not affect the function of the original needle, either injection dose or treatment, and the improved performance is better than traditional ones. However, only the mosquito is observed as bionic object now, the biological prototype is too limited and microscopic structure of insect fascicles observation seems not comprehensive enough. Based on the existing research, this paper has done further research on insects with sucking fascicles, such as mosquitoes and cicadas two kinds of insects, combined with its smoked form, observed the micro-structure of fascicle with the help of scanning electron microscope, analyzed the relationship between micro-structure of fascicle and piercing resistance in quantity, then present a bionic models for needle surface bionic design, finally simulated human skin with silica gel, in universal testing machine needle on bionic common needle, piercing resistance measurements were compared to verify the drag reduction effect, provided evidence for enriching and improving the research and preparation of bionic needles.

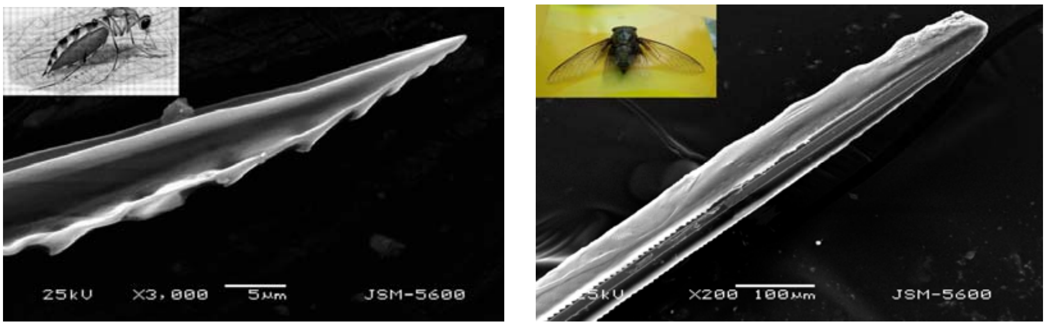
## 2. INSECT FASCICLE MICROSTRUCTURE

From Changchun city, Jilin Province to field collection of aedes, and from linyi city and liaocheng city, Shandong province to field collection of shanxi ZhaChan as biological specimen, which were all dissected under style microscope, the process of the microscope magnified to 50~90 times, then placed the anatomic fascicle in scanning electron microscope (SEM) under observation. Considering the two kinds of insects snorting mechanism (KONG &WU, 2009; Ramasubramanian et al., 2008; Daniel & Kingsolver, 1983), this paper mainly choose fascicle as the main object of observation which answers for pierce the host organization function, such as mosquitoes lower jaw and cicadas upper jaw.

Serrated triangular microstructure distribution were found on insects fascicle, distributed respectively in mosquitoes front jaw fascicle (Figure 1-a), and the cicada’s maxilla fascicle front end (Figure 1-b). To quantify the two kinds of insect fascicle triangular sawtooth surface morphology, this article uses the sawtooth height of six characteristic parameters to describe the parameters, the corresponding relationship shown in Figure 2, the measurement results shown in Table 1.

From the measurements found that there are difference among mosquitoes and cicadas of two insect fascicle in the triangular serrated micro-structure either in size or shape, differed as follows: the mosquito has the small micro-structure size, cicadas micro-structure has larger one; the forward angle of mosquitoes microstructure is greater than the backward one, triangle tilts to the rear part of the fascicle, while the forward angle of cicada's micro-structure equals to the backward one, its microstructure is symmetric on bottom corner.

Discrepancy in fascicle microstructure among the two kinds of insects mainly depends on different piercing-sucking objects of two kinds of insects. Mosquitoes’s sucking objects are mainly the animals and humans, while the cicadas sucking objects are plants, the structural organization of plant epidermis is sparse than that animal tissues, and its anti-penetration ability should be less than that of animal's skin (ZHENG, 1988; Wildnauer et al., 1971; Gardner & Briggs, 2001; Mehta & Wong, 1973; Elkhyat et al., 2004) , while the cicadas penetrate plant need less power, therefore the cicada's upper front maxilla micro-structure is not significant.




(a) Mosquitoes jaw (b) Cicada maxillary

**Fig. 1: Microstructure of insect fascicle**

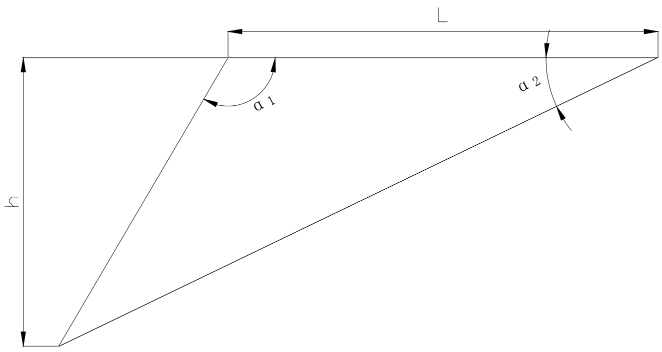



**Fig. 2: Fascicle triangular diagram of sawtooth microstructure**

**Table 1: fascicle microstructure size**

| Characteristic parameters | Mosquitoes jaw | Cicada maxillary |
|---|---|---|
| Sawtooth height h/μm | 1.2 | 17.7 |
| Sawtooth width d/μm | 2.7 | 44 |
| Sawtooth line density /piece/mm | $3.7\times10^5$ | - |
| Sawtooth forward angle $\alpha_1$/ ° | 79.1 | 22 |
| Sawtooth backward angle $\alpha_2$/ ° | 25.2 | 25 |
| Fascicle length L/mm | 1.8 | 18 |

# 3. BIONIC NEEDLE DESIGN AND DRAG REDUCTION EFFECT

## 3.1 Design of Bionic Needle

Through research on the micro-structure of the two kinds of insects fascicle and analysis of piercing power influencing factors, found that the non-smooth micro-structure fascicle that contributing to piercing reduces the resistance to a large degree. Based on the above results, and referred that the mosquitoes and cicadas have the same microstructure characteristics of sawtooth triangular fascicle, combined with syringe needles processing, we designed and fabricated the serrated bionic needles. Serrated structure are rolling fabricated with simple self-made small lathe on common medical needle no.12 surface, made in Changchun syringe plants, shown in Figure 3.

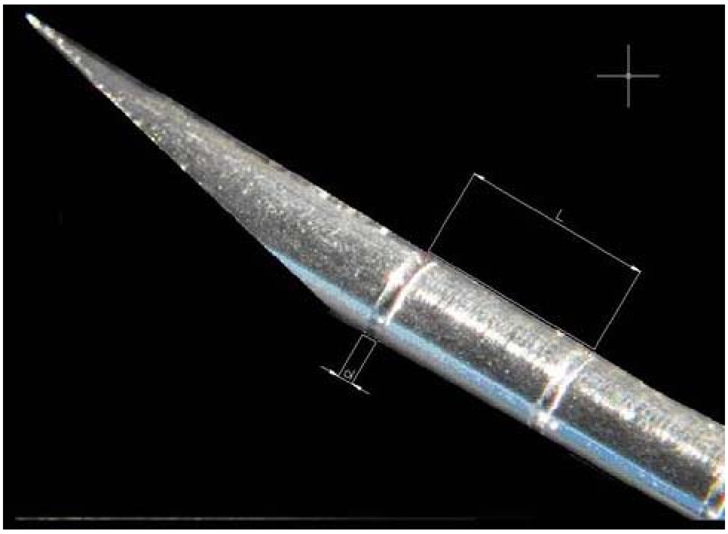



**Fig. 3: Bionic needle**

## 3.2 Puncture test

To verify the drag reduction effects of bionic needle, we chose four kinds of bionic needles and a common needle to perform penetration resistance test in WSM_100N universal testing machine (Changchun Intelligence Co., Ltd.), verified the drag reduction effects of bionic needles. During the experiment, the syringe penetrated simulation of silica gel vertically at speed up to 100mm/min, into depth 15mm. Each sample measured three times and figured out the average amount. Since the structure of human body simulation silica gel is relatively uniform, and its hardness of elasticity is similar to human muscle tissue, the simulation silica gel was used as test medium instead of human body skin in the experiment, bionic needles structure size shown in Table 2.

**Table 2: Bionic needles size**

| size / sample | Sawtooth depth h ( mm ) | Sawtooth width d (mm) | Sawtooth gap L ( mm ) | Non smooth ratio |
|---|---|---|---|---|
| 1 | 0.08 | 0.1 | 0.75 | 13% |
| 2 | 0.08 | 0.2 | 0.75 | 27% |
| 3 | 0.08 | 0.3 | 2.5 | 12% |
| 4 | 0.08 | 0.4 | 1.75 | 23% |

Resistance value was evaluated through respective power analysis of different size needles when piercing through the media. To study the drag reduction effect of bionic needles, this paper selected Reduce work efficiency as the drag reduction index. Reduced power efficiency is defined as:

$$R = \frac{W_0 - W_i}{W_0} \times 100\% \qquad (1)$$

Where, R that reduce work efficiency, $W_0$ that power value of smooth specimen, $W_i$ that specimen power non-smooth values.

### 3.3 Test results and analysis

#### 3.3.1 Test specimen and the resistance of silica gel

Figure 4 for the piercing resistance curve of the common needles compared with the bionic ones. The smaller as the area under the curve is, the less of sample work did during the penetration process. According to the formula (1) we can calculate each sample by the relative power efficiency of common needle. By the chart, the bionic needle working were less than common ones, of which the best drag reduction is sample 2, its reduction in the effectiveness decreased 19% to the smooth needle; followed by sample 4, reduced efficacy rate by 14%; Sample 1 was 13 % less effect; specimen 3 by the smallest power efficiency, as 11 percent.

The experimental results show that the bionic needles have achieved a relatively smooth, better drag reduction effect, and the sample 2, the best drag reduction. The bionic needle structural optimization study testifies, the width and distance factors of the needle serrated structure influence drag reduction effect significantly, these double factors had a nonlinear relationship with the needle drag reduction, besides that, the interaction between the two factors should be also considered. In this experiment, the width and distance factors combination in sample 2 achieved the best drag reduction effect, Showed that the depth of the micro-structure factors and form factors of the same premise, the greater the area ratio of non-smooth, micro-structure to achieve drag reduction effect is.

#### 3.3.2 Mechanism of drag reduction of non-smooth surface

(1) Contact area impact on the piercing resistance

The non-smooth surface micro-structure contributes to reducing the actual contact area between the needle and the "skin", consequently reduces the piercing resistance of needle. According to Davis S micro-needle piercing force formula (Davis et al., 2004), under the same conditions, the contact area between the needle and skin is the main factor of piercing resistance. Bionic needle surface microstructure increases the area of non-smooth surface, decreases the actual contact area, the needle drag reduction capacity improves accordingly. Sample 2, the largest non-smooth area ratio as well as the smallest actual contact area, where the least piercing resistance exists; Sample 3 the smallest non-smooth area as well as the largest actual contact area, however, acquired the greatest piercing resistance.

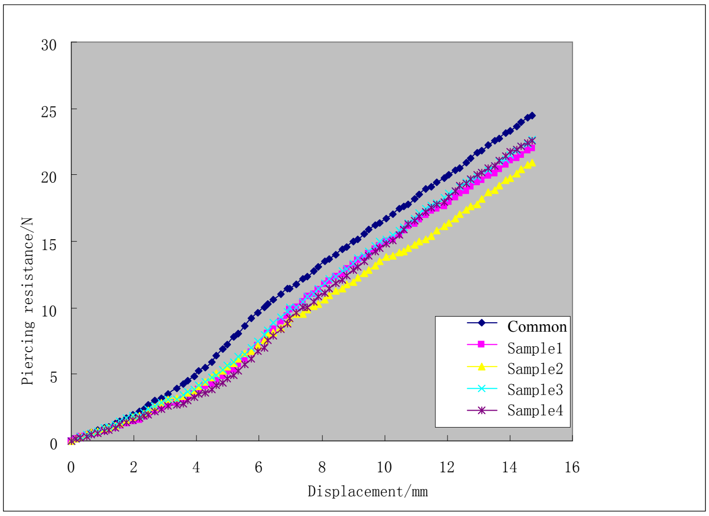



**Fig. 4: Needle pierced resistance curve of contrast**

(2) Rolling friction resistance influence on the Piercing

The microstructure of the bionic needle forms rolling friction between the needle and body fluid, sequentially reduces needle piercing resistance. The surface microstructure of needle forms gap to skin's non-smooth parts, when the needle contacts with the skin, with the fluid flow, air traps in the micro-structure of fascicle within the slit and formed hole to constitute the capillary (Scherge & gorb, 2004), body fluid can not enter the micro-structure, therefore reduce the actual contact area between needle and skin, body(blood) fluid form rolling friction on needle surface. In contrast, smooth surface, the body contact between particles and needle surface area are large enough to attach body (blood) needle to the surface of fluid, it will move in slide mode between body (blood) fluid and needle, the needle suffers larger friction when forwarding (JIANG &FENG, 2007). Test 2 area ratio of non-smooth the largest, the minimum friction exist between the needle surface and the contact surface, drag reduction the best.

## 4. CONCLUSIONS

Based on existing research results on Bionic needles, this paper has done further research with sucking fascicles of the insect, with mosquitoes and cicadas two kinds of insects as examples, observed the microstructure of fascicles by scanning electron microscope, found that the microstructure of the two kinds of insect differs either in size or shape, mainly due to different piercing target and different process of overcoming the piercing resistance. According to the research results, bionic model was extracted and bionic designed, then manufactured bionic needles, through needle puncture tests verified the drag reduction effect of bionic needle, the greater non-smooth area ratio of the bionic needle has, the better does the drag reduction effect. As for the drag reduction mechanism, the bionic needle reduces the contact area between needle and skin, forms the rolling friction style consequently reduces the piercing resistance.

Depth study of insect fascicle provide a basis for bionics to improve the medical needle, such as syringes, biopsy needles, micro needle surface structure and reducing resistance, this study can be also applied to other devices with piercing capabilities, such as nails, drills, etc.

## REFERENCES

Davis S P, Landis B J, Adams Z H, Allen M G. Prausnitz M R. (2004). Insertion of microneedles into skin: measurement and prediction of insertion force and needle fracture force[J]. *Biomechenical, 37(8)*: 1155–1163.

Davis S P, Martanto W, Allen M G, Praunitz M R. (2005). Hollow Metallic Microneedles for Insulin Delivery to Diabetic Rats*[J]. IEEE Transactions* on *Biomedical Engineering, 52(5)*：909-915.

Daniel T L , Kingsolver J G. (1983). Feeding strategy and the mechanics of blood sucking in insects [J]. *Theor.Biol, 105:* 661–72.

Elkhyat A, Courderot-Masuyer C, Humbert Ph. (2004). Influence of the hydrophobic and hydrophilic characteristics of sliding and slider surfaces on friction coefficient: in vivo human skin friction comparison. *Skin Research* and *Technology, 10(4)*: 215-221.

Gardner T N, Briggs G A D. (2001). Biomechanical measurements in microscopically thin stratum corneum using acoustics[J]. *Skin Research* and *Technology*, *7(4)*: 254-261.

Griss P, Stemme G. (2003). Side-Opened Out-of-Plane Microneedles for Microfluidic Transdermal Liquid Transfer[J]. Microelectromechanical *Systems, 12(3)*：296-301.

JIANG lei, FENG lin. (2007). *The bionic intelligent nano interface material [M]*. Beijing: chemical industry press, 122-123.

Kersten, Gideon, Hirschberg. (2007). Needle-free vaccine delivery[J]. *Expert opin drug delivery, 4(5),* 459-474.

KONG X Q, WU C W. (2009). Measurment and Prediction of Insertion Force for the Mosquito Fascicle Penetrating into Human Skin[J]. *Bionic Engineering. 6*:143-152.

LI yan,QI xin,WAN yanling. Experimental design method in structural optimization of bionic needle application[C].

MacDonald E, Canino JV. (2007). Nonlinear response of plain-orifice injectors to nonacoustic pressure oscillations[J]. *Propul power, 23 (6)*: 1204-1213.

Mehta A K, Wong F. (1973). *Measurement of flammability and burn potential of fabrics*. Full Report from Fuels Research Laboratory, MIT, Cambridge, Massachusetts.

M K Ramasubramanian, O M Barham , V Swaminathan. (2008). Mechanics of a mosquito bite with applications to microneedle design. *Bioinsp [J] .Biomim.3*: 046001.

M. Scherge, S. gorb. (2004). *Micro/nano biological tribological——Natural selection [M]*. Beijing, machinery industry press, 6: 50-61.

O'Shaughnessy, Paul J. (1998). Injector geometry effect on plain jet airblast atomization[J]. *American society of mechanical engineers, 12(6)*, 8.

Park J H, Allen M G, Prausnitz M R. (2005). Biodegradable polymer microneedles: Fabrication, mechanics and transdermal drug delivery[J]. *Controlled Release, 104(1)*: 51–66.

QI yingchun, LI yan, JIN jingfu, etc. (2009). Research painless injection technique [J]. *Medical Equipment*, *30 (9)*: 34—36.

Stachowiak, Jeanne C. (2007). Piezoelectric control of needle-free transdermal drug delivery[J]. *Control release, 124 (12)*: 88-97.

Stephanie P. (2002). This won’t hurt a bit [J] .*New Scientist, 173*: 8

Vandervoort J, Ludwig A. (2008). Microneedles for transdermal drug delivery: a minireview[J]. *Frontiers in bioscience publications, 13*: 1711-1715.

WANG jingchun, CHEN lili, REN luquan, etc. (2008). Experimental Study on Drag Reduction Bionic syringe needles[J]. *Jilin university journal (engineering).38(2)*: 379-382.

Wildnauer R H, Bothwell J W, Douglass A B. (1971). Stratum corneum biomechanical properties: I. Influence of relative humidity on normal andextracted human stratum corneum[J]. *Investigative Dermatology, 56(1)*: 72–80.

ZHENG zhifang. (1988). *Bark chemistry and using [M]*. Beijing: China's forestry press, 23-55.

Ziegler, Andreas. (2007). Needle-free injection--science fiction or comeback of an almost forgotten drug delivery system[J]. *Med monatsschr pharm, 30 (8)*: 297-303.