Study on the body girth dynamic size for wetsuit ease design

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Abstract: The aim of this exploration is to research on how the body measurements change under deformation during diving. We measured 31 body measurements of 57 females in six postures including four postures on the land and two postures under the water. We compared the body measurements, especially focused on the differences between standing and laying prone postures, and check the pattern and pressure with virtual method. It will help designers to find the reasonable dynamic ease and apply it to the pattern block design of wetsuit.

1. Introduction
The divers work under water with different dynamic postures [1], so, skin deformations should be taken into consideration for ease allowance calculating [2]. If the wetsuit is too loose, the water will invade diver’ insulation system, if the wetsuit is too tight, the diver meet the difficulties to swim, because the compression wetsuit will be influenced [3]. To minimize the flowing water between the skin and clothing during diving process, which mainly depends on diving suit’s pattern structure, fabric insulation performance and special craft [4], a dimensional change of body in dynamic positions is a complex issue that cannot be considered only from the aspect of basic anthropometric measurement, but the body morphology parameters must be taken into consideration [5]. Some researches about wetsuits only focused on the body standing postures [6]. Our research focuses on the girth under dynamic changes and the corresponding ease values on laying prone postures underwater. Besides, 3D software technology is used to simulate the wearing effect of virtual wetsuit based on 2D pattern block.

2. Experiment steps
1) Four materials M1…M4 are as shown in Table 1. Firstly, we used non-elastic material to test the maximum decrease values $\Delta G$ of 11 body girths, 15 testers, to simulate the maximum squeeze change of hydraulic pressure; and used four kinds of materials (M1…M4) in warp and weft directions respectively to stretch different body girths (11 measurements, each part are measured in front, side, back) until to maximum elongation $E_M$ and maximum possible pressure $P$ for each tester, as shown in Figure 1.

| No. | Side layers | Middle layer, % | Thickness, mm | Level |
|-----|-------------|-----------------|---------------|-------|
| M1  | Nylon       | 100% CR         | 2.85±0.07     | High-end |

Table 1. Experimental materials
2) Then we used body surface drawing line method to record body size changes of 31 body sizes of 57 female bodies when postures (based on some typically diving actions) change. The subjects completed two standing and two laying prone postures on the floor and two laying postures under water. We used next abbreviations P0, P1, P2, P3, P4, and P5 to describe each posture, as shown in Figure 2.

- Posture0 – natural standing postures on the floor;
- Posture1 – standing and hands up on the floor;
- Posture2 – laying prone on the floor;
- Posture3 – laying prone and legs curl the floor;
- Posture4 – the same as “Posture2” but under water;
- Posture5 – the same as “Posture3” but under water;

Finally, we applied basic zero ease in wetsuit pattern to obtain a new pattern block.

### Table 2. Maximum elongation of materials and pressure

| Max average values | M1  | M2  | M3  | M4  | Mean     |
|--------------------|-----|-----|-----|-----|----------|
| $E_M$ in warp %    | 19.5| 10.8| 9.5 | 12.7| 13.1 ± 4.4|
| $E_M$ in weft, %   | 21.2| 19.7| 11.5| 20.4| 18.2 ± 4.5|
| P, kPa             | 1.90| 1.97| 2.39| 1.92| 2.05 ± 0.23|
3.2. Dynamic size change of human body

The differences of BG, WG, HG, TG, and SL are shown in Figure 3. The maximum difference of BG_F, WG_F, HG_F (and BG_B, WG_B, HG_B) took place between the postures P5&P0. In the circumstance of hands up (set in the same breathing state), the bust line moves upward, the side seam moves forward, the abdomen bulge, the hip, and thighs changed a little. As shown in Table 3, we obtained the dynamic changes of the human body: BG is 0, to WG is -1.3%, HG is -1.1%, TG is -0.2%, and SL is 4.4%.

As for wetsuit pattern design, the minimum negative values are applied to fit the human body and satisfy the dynamic change, but, the positive values (such as BG_B) are not considered as additional ease.

![Figure 3](image)

*Figure 3. The average differences between body measurements for body type A, %*

| The average differences of body girths | The average differences of girths front and back part |
|---------------------------------------|-----------------------------------------------------|
|                                         | BG_F, BG_B  | WG_F, WG_B  | HG_F, HG_B  |
| P1&P0                                 | -2.2/1.1    | -0.6/0      | 0.2/-0.1    |
| P2&P0                                 | -3.8/6.7    | -1.2/-0.2   | 0.7/-2.4    |
| P3&P0                                 | -4.0/6.7    | -1.2/-0.1   | -0.2/-0.5   |
| P4&P0                                 | -4.6/6.4    | -1.4/-0.4   | 0.9/-3.1    |
| P5&P0                                 | -4.9/6.5    | -1.3/-0.1   | 1.0/-2.0    |

3.3. Pattern adjustment and design

We applied the minimum design ease value to original basic pattern (for keep tight under dynamic conditions), then, an adjusted pattern is designed – New basic pattern 1. - The ratio we obtained based on previous experiments – the material elongation/the body girth decrease, $R_C = (E_M / ΔG)$, $ΔG$ is dynamic girth changes as the ratio of compression capability of material, which can be used to calculate the average elongation when the body girth is decreased per 1%, $R_C = -2.45 ± 0.80$. Therefore, multiply $R_C$ the minimum design ease in pattern block $BG$ is 0, $WG$ is -3.19%, $HG$ is -2.70%, $TG$ is -0.49%, but $SL$ is 4.4%.

In response to this change, we used the 2D graphics software Richpeace CAD, to make careful adjustments to the basic pattern, and redesigned the structural style. As Figure 4 shows, the difference between two patterns is obvious.

Figure 5(a) shows, new design “new pattern 2” is based on the “new basic pattern 1” but with raglan sleeve, cutting lines and side piece. The new cutting lines are designed according to body morphology and diving postures characteristics with different colors.
Figure 5(b&c) shows the virtual try-on effect with static standing posture, the corresponding 2D “new basic pattern 1” and “new pattern 2” on body type A (BG=81.5, WG=65.7, HG=90.4, cm), both patterns with minimum design ease we mentioned.

**Figure 4.** Original basic pattern with zero ease (in dot line) and new basic patterns 1 (in solid line)

**Figure 5.** Patterns and virtual try-on: (a) – new basic pattern 1 (in dot line) and new pattern 2 (in solid line); (b) – dressing effect with static standing posture and the corresponding new basic pattern 1; (c) – new pattern 2

3.4. Simulation test

In order to check new patterns and simulate the real material properties and the real wearing effect, we adjusted the key data of virtual fabrics properties, marked the key points (174) in CLO software, as shown in Figure 6(a). We take the fabric M2 as an example.

As shown in Figure 6(b). We cannot make an accurate objective conclusion from the wetsuit appearance, the virtual pressure values can explain the fit degree. In total, the range between the maximum and minimum virtual pressure of basic patterns is significantly, the values at the waist and arm are smaller relatively. The fitting degree of original basic pattern is not enough, but, the new basic pattern 1 with the minimum design ease value is tighter than original basic pattern at the girths of waist, hip and thigh, the pressure values change from bust to thigh is small. The new pattern 2 has relatively higher and comfortable pressure value, which is much tighter than the former 2 patterns.
The basic patterns have few change when we add the minimum design ease value, because we stretched four kinds of fabrics to the max length of one direction, the other direction shrink less than 3%. We only simulate seamless and more seams patterns (new basic pattern 1 and new pattern 2), the surface fit degree can be shown through the deformation/elongation. However, the new basic pattern 1 without some cutting design shows that the wetsuit is not fit enough and the ability to resist motion deformation/elongation is poor, as shown in Figure 7.

**Figure 7.** Fabric deformation/elongation: (a) – New basic pattern 1; (b) – New pattern 2

4. Conclusion
According to this experiment, those results can predict how dynamic postures influence the body sizes, which can be connected with the pressure on soft tissue, tensile property of materials and parameters of pattern block, and further applied to solve the problems under wetsuit pattern block design.

Under this study with different dynamic postures, we established the relations between their size changes, which provides the possibilities for complex studies of body measurements in dynamic conditions.

Through the use of 2D and 3D technology, we can modify the old pattern and design new style wetsuits, and even simulate some real properties such as the contact performance after adjusting 3D parameters. After continuous adjustment, the new pattern has a better try-on performance and the final pattern can be directly used for factory efficiency production inspection, omitting the repeated actual manufacture modifying works.

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