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Clothing Protecting Brachial Plexus of Motorcycle Rider during Collision

Abstract
Our research was motivated by medical reports concerning special cases of motorcycle accidents, in which the riders suffered a tragic injury - the tearing-off of the roots of the brachial plexus from the spinal cord. Such an injury cannot be treated, and cripples the victim for life. The article describes the scope of the problem, the epidemiology and the mechanism of the brachial plexus injury, as well as medical assumptions and general material and construction assumptions for the development of the clothing to protect the brachial plexus, and the effectiveness of protective clothing regarding safety against injury to this part of the human body.

Key words: *protective clothing, brachial plexus, motorcycle accidents, traffic accidents.*

Introduction

Statistical analyses of traffic accidents carried out in the 1980s and 1990s in the 15 most industrially developed European countries indicate that the number of lethal accidents of motorcycle riders constitutes c. 9% of the total number of traffic accidents. It is estimated that the number of motorcycles in these countries in 1993 amounted to approximately 8.6 million, and the number of lethal accidents among motorcycle drivers was approx. 5000 a year [1]. Considering the rapidly growing interest in the motorcycle as a means of transport, especially in crowded cities, as well as the increased interest in the motorcycle as a fashionable pastime, the issue of motorcycle riders' safety acquires an important social dimension.

On the basis of research carried out in Germany, it was demonstrated that every thirteenth motorcycle user is subject to an accident. The death rate in motorcycle accidents is four times higher than in the case of car accidents. The victims of such accidents are mainly young men between 20-30 years of age [2]. One class of motorcycle accident which is most dramatic in its consequences is the collision leading to a special kind of brachial plexus injury - the tearing-off of the roots of the cervical-brachial plexus from the spinal cord. At the moment, such an injury cannot be treated. The victims have no chance for either treatment nor pain relief in the upper limb. It is assumed that the mechanism of the brachial plexus injury proceeds as follows: as a result of the motorcycle accident, the rider hits his shoulder or the front surface of the neck against a rigid obstacle, at the same time deflecting his head in the opposite direction.

According to data gathered by the Institute of Motor Transport in Warsaw, in Poland in the course of traffic accidents in 1996, 245 motorcycle riders died, and 2850 were injured. The total number of accidents of motorcycle riders amounted to 3078 cases. The probability of an injury during a motorcycle accident is 93%. It is estimated that there are c. 80,000-90,000 motorcycles in Poland.

Considering the high social cost and suffering of the victims, special clothing for motorcycle riders to protect them during accidents, with special attention to the protection against injury to the cervical-brachial region, was developed as part of a research project carried out by the TRICOTEXTIL Institute of Knitting Techniques and Technologies in Łódź.

The aim of this article is to present the preliminary analysis of the problem, a brief description of the methods and means used for its solution, as well as the present state of the project's development and future plans. Material selection, detailed design description and test results will be the subjects of future articles.

Epidemiology and Consequences of Brachial Plexus Injury. Experiences of the Department of Neurosurgery, Military Medical Academy, Łódź, in the Treatment of Brachial Plexus Injuries

On the basis of data from literature concerning brachial plexus injuries, motorcycle accidents are regarded as the most dangerous, constituting 51% of the total number of the analysed cases of brachial plexus injuries [3]. The fact that brachial plexus injuries are most often caused by motorcycle accidents is confirmed in Table 1, which was compiled on the basis of data gathered by the Department of Neurosurgery, Military Medical Academy in Łódź.

In [4], the authors concluded that because of a lack of any effective method for treating brachial plexus injuries, it is necessary to develop special protective clothing for this group of riders. This clothing should:

- reduce the possibility of the back-movement of the shoulder under the injuring force,
- limit the movement of the receding shoulder in relation to the neck and head, both of which are reflexively moving away,
- protect the collar-bone against fracture, and the brachial plexus against direct injury.

Table 1. *The reasons for brachial plexus injuries treated in the Clinic in the period from 1982 to 1990.*

Reasons for brachial plexus injuries	Number	%
Motorcycle accidents	69	61
Automobile accidents	22	19
Pedestrians hit by automobiles	9	8
Other, incl. falls, industrial accidents, accidents during physical training	14	12
TOTAL	114	100

The Model of Brachial Plexus Injuries

It is assumed that the mechanism of brachial plexus injury is as follows: as a result of the motorcycle accident, the rider hits his shoulder or front surface of the neck against a tree, pole or other vehicle, at the same time deflecting his head in the opposite direction [5,6]. The head movement is abrupt and sudden, occurring in milliseconds. This situation causes the shoulder girdle to retract down and back, and generates great tensions in the nerve elements of the brachial plexus, especially in its upper part. As a result, at great impact force, the roots of the brachial plexus may be torn out from the spinal cord, and the plexus may be strained or broken. In the case of direct impact on the collar-bone, the plexus may be damaged by bone splinters from the broken collar-bone; it may be crushed between the collar-bone and the first rib; or it may be pressed against the lateral appendages of the cervical spine.

The position in which extreme stretch (tearing off) of the brachial plexus occurs, is the effect of exceeding the physiological movement range of the following elementary movements (in case of the right brachial plexus injury): bending the head and the cervical spine to the left and back, and movement down of the right shoulder (Figure 1).

Medical Assumptions for the Elements Protecting the Shoulder and Brachial Plexus and the Pectoral-Lumbar Part of the Spine

Considering the mechanism of the injury as described above, the following zones on the surface of the rider's body were designated for covering by protectors made of materials with high capability to absorb kinetic energy:

Zone I

Protection of the lower part of the cervical spine against movements causing stretching of the brachial plexus. Zone limits: 1/2 - 1/3 of the lower part of the neck.

Protector's tasks:

- absorbing the injury energy and diminishing the injury force,
- ergonomic co-operation with protective helmet.

Zone II

Protection of the shoulder against direct mechanical injury.

Zone limits:

- top-paracentral: the neck-shoulder region,
- lower front: the bottom edge of the collar-bone,
- lower back: the crest of the shoulder blade,
- side: the deltoid muscle.

Protector's tasks:

- absorbing the injury energy and diminishing the injury force,
- protection against fractures of collar-bone and shoulder blade, and against direct injuries to the brachial plexus.

Zone III

Protection of the pectoral-lumbar part of the spine.

Protector's tasks:

- protection against excessive backwards deflection of the spine,
- diminishing the injury energy,
- transmitting part of the injury energy to the hips.

On the basis of the above medical assumptions, material and construction assumptions for the motorcycle rider's protective clothing have been prepared.

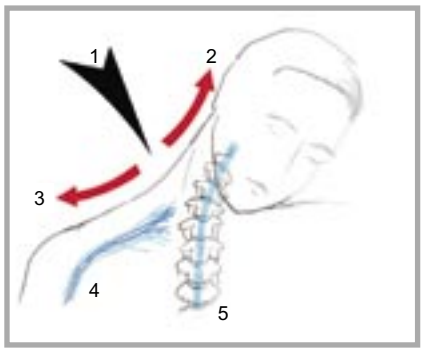

Figure 1. *Scheme of brachial plexus tearing-off from spinal cord; 1 - impact stroke on neck, 2 - abrupt movement of head, 3 - abrupt movement of shoulder girdle, 4 - brachial plexus nerves, 5 - spine with spinal cord.*

Computer Simulation of the Motorcyclist's Fall onto the Shoulder, Considering the Susceptibility of the Protective Clothing, with the Use of the MADYMO Programme

Within the scope of this research work, the Institute of Aeronautics and Applied Mechanics of Warsaw Technical University undertook efforts to establish whether a computer analysis of a motorcycle accident with the use of the MADYMO programme [7] is possible, and whether it is possible to estimate the forces operating on the head and shoulder of the rider at the moment of hitting the ground. A simplified version of shoulder protection was also modelled. The simulation was carried out with the use of the MADYMO programme, which was developed for the purpose of dynamic analysis of multi-body systems, and in its recent version has been enhanced by the possibility of adding models created with the use of the Finite Elements Method (FEM).

The analysis of multi-body systems is based on estimating the trajectories of the system's separate elements (the non-deformed parts), as subject to different forces, such as gravitation or contact with other bodies. The parts are connected by joints which possess a certain movement scope and rigidity. Each body has a given mass, as well as moments of inertia and position at the starting time. On the other hand, the Finite Elements Method is based on the division of the body into small sections that can be deformed. The Method allows for estimation of body deformation and forces of environmental reaction (contact forces with rigid bodies, such as multi-body forces), and internal forces, i.e. tensions. The advantage of this method is the possibility of accurately reconstructing the geometrical shape of the object under consideration. The method's main disadvantage is high time consumption during the modelling and the longer time of computer calculations.

A big difficulty in modelling was the simulation of the rider's fall in the given position, at which the probability of tear-off of the brachial plexus roots is the highest. To start with, film material from a Formula 1 motorcycling event was analysed. The film illustrated the accidents of professional sportsmen, whose preparation to fall is much better than that of an average rider. Riding on a race track, even at much higher speed, is much safer than riding on public roads, because the track is well prepared and lacks any obstacles.

The following simulations of traffic accidents were prepared:

- collision of the motorcycle with a car,
- collision of the wheel onto the kerb, resulting in a sudden turn of the vehicle, and catapulting the rider into the air,
- skid of the motorcycle as a result of rapid stop,

- collision of the motorcycle with a rigid obstacle, catapulting the rider into the air, in the course of which the rider hits a pole or similar object with his shoulder and neck,
- collision of the motorcycle with a wall, where the rider hits the wall first with his head, next slides down the surface of the wall, bending the neck to the left, and then hitting the wall with his shoulder.

The latter situation is the closest to actual conditions during the fall, resulting in severe damage of the shoulder and the ripping off of the brachial plexus' roots from the spinal cord.

The simulation for the FEM uses two initial models of protection for the rider's shoulder, flat and cylindrical. The first models of protective pads were made of resilient materials. The degree to which the hitting force is limited by the protective pad depends on the pad's material properties, and most of all on its ability to absorb kinetic energy. It is necessary to establish these values with the use of adequate dynamic tests, e.g. by the method described by Standard PN-EN 1621-1:1997.

The constraints to further development and verification of the motorcycle accident simulation at the present stage are as follows: lack of information about the viscoelasticity parameters of the protective pad used, and of data on the human body's reaction - in this case of the shoulder - to the accident. In order to continue further research with the use of the MADYMO programme, the following steps are planned: to introduce the specific dimensions of the protective pad and its material properties to the model, to improve the neck model, to test the tension of the flexible connector modelling the nerve bundle, to test the influence of the dislocation of some neck muscles on the tension of the brachial plexus, to introduce the model of a breakable collar-bone, and possibly to create the model of a shoulder blade.

Material and Construction Assumptions for Motorcycle Rider's Protective Clothing

The research project was preceded by a thorough analysis of notional possibilities concerning textile materials and plastics. The Project used a rich bibliography and multiple scientific experiences carried out in the course of our contacts with national and foreign centres dealing with traffic accidents and traffic safety.

It was assumed that a multi-layer clothing would be developed in which the outer layer would be made of knitted or woven fabric, depending on the usage requirements, and the inner layer would be made of knitted fabric. The two layers would be separated by shock protectors made of solid and micro-porous plastics, placed in the waistcoat made of distancing knitted fabric of special construction, which would constitute a foundation for the protectors.

The materials for the outer layers were selected to meet the following high requirements:
- tear and abrasion resistance, both of knitted and woven fabrics,
- rain and wind resistance of woven fabric,
- elasticity of knitted fabric,
- good visibility of the clothing's elements in every kind of light, according to standard PN-EN 471:1997 [8].

The inner layers (underwear and lining) should guarantee air permeability and sweat (steam) drainage outside. The shock absorbing layers should meet the requirements of high energy suppression according to standard PN-EN 1621-1: 1998 [9]. In the design, the designers principally concentrated on protecting the shoulder girdle and neck, following established medical assumptions.

Choice and evaluation of materials

The outer layers of the clothing were made of water-resistant woven fabrics. The knitted fabrics for these outer layers were developed in the TRICOTEXTIL Institute. Strength was seen as the most important parameter. In the knitted fabrics which were developed, the inside has a special 'velour' surface, guaranteeing the 'transfer' of friction forces onto further layers of the clothing, thus prolonging the action time of maximal force. The materials which ensure the protective, anti-shock features of the motorcycle rider's clothing are adequately placed protectors made of micro-porous rubber or of other foam plastics, which meet the requirements of standard PN-EN 1621-1: 1998. Details concerning the selection of this material will be the subject of next article.

Design and construction

The clothing was designed as a series of multilayer systems, meeting specific functions - protective, ergonomic, biophysic, and aesthetic. While developing the construction of the clothing, the layer system had to be considered and the types of seams, methods of fastening and placing on the rider's body, and shaping the separate elements of the clothing selected.

The most important protective function in the motorcycle rider's clothing is played by the waistcoat with anti-shock protectors and a bolster collar. The main proposal was the use of a waistcoat as an inside layer. However, the waistcoat with the bolster collar can also be worn as an outside layer on other kinds of clothing, for example, with elbow and shoulder protectors .

Because of their shape, the protectors co-operate with each other, protecting the cervical, pectoral and lumbar vertebrae, the shoulders, and the upper part of the arm. Co-operation means a mutual effect on the juncture of trimmed containers on the carrying parts of the waistcoat. An important element of the protective clothing is the bolster collar made of micro-porous rubber. Its role is to protect against excessive back and side deflection of the head during the fall and the strike. To ensure this, the part of the collar was strengthened with a rigid, anatomically-shaped composite base made of Kevlar fabric and acrylic resin. Schematic views of the protective clothing we designed and manufactured are presented in Figure 2, and photos of the strengthened part of the collar are seen in Figure 3.

Methods of Testing the Waistcoat with Built-in Protective Pads

Testing the effectiveness of the bolster collar

The tests of the effectiveness of the protection offered by the waistcoat should be carried out in conditions close to the conditions of an actual accident. These can be obtained in the following ways:
- a computer simulation of a motorcycle accident. However, the MADYMO simulation, as the first, pioneering work of this type, at the current stage does not allow its full possibilities to be used.

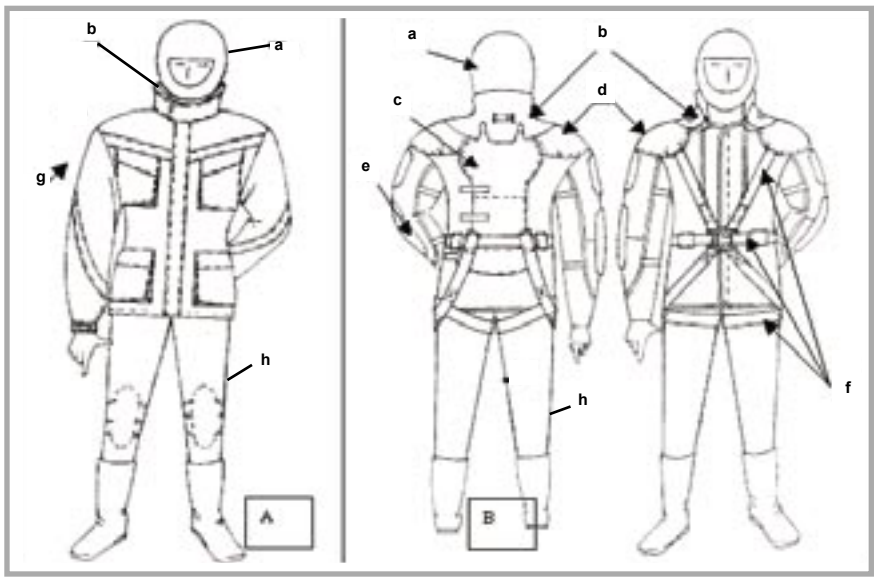

Figure 2. *Motorcyclist's protective clothing: A - outer jacket and protective trousers, B - waistcoat with impact protectors and bolster collar: back and front view: a) helmet, b) bolster collar, c) back protector, d) shoulder protectors, e) arm and elbow protector, f) fasten belts, g) enter jacket, h) protective trousers.*

- dynamic tests, performed with the use of dummies used in crash-tests.

Presently, in foreign laboratories working on automobile and passenger safety, crash-tests are performed with the use of Hybryd III dummies. Dynamic crash-tests for cars, with the use of the Hybryd II dummy are carried out by the Industrial Institute of Motorisation, Warsaw. Tests simulating motorcycle accidents have so far not been carried out in Poland.

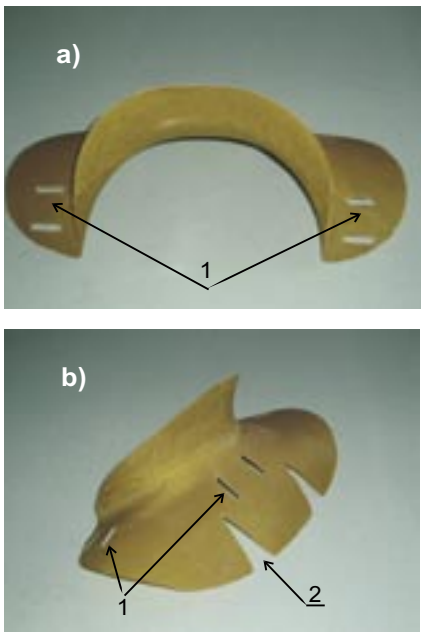

Figure 3. *The rigid part of bolster collar: a) front view, b) back view, 1 - slits for fastening the collar to the waistcoat, 2 - additional slits for increasing the collar's elasticity.*

In order to test the effectiveness of the bolster collar in limiting the excessive back and side neck deflection during a crash at a given speed, a special post was prepared, at which it was possible to compare the deflection of the head and neck of the Hybryd II dummy, dressed in protective waistcoat, both with and without the bolster collar. The dummy, placed backwards at a 45° angle to the direction of the 'ride', was fastened to the catapult carriage, accelerated by spring ropes. The torso of the dummy was placed vertically, and the head was bent forward at an angle of 30°. The carriage was accelerated to the speed of 30 km/h, and was then abruptly stopped by a special brake.

At the moment of stopping the carriage on the hydraulic buffers, the head and neck abruptly deflected back and sideways, due to high inertia forces. The triaxial accelerometers built into the dummy registered the change of retardation of the head and torso. The experiment was filmed by a high-speed camera. The comparison of the trajectories of a chosen point on the dummy's head proved that head deflection with the use of the rigid-base collar was c. 10% smaller than the head deflection without the collar.

Tests of kinetic energy absorption by micro-porous materials used in anti-shock protectors

The effectiveness of the shoulder and back protectors was analysed by testing the energy absorption of micro-porous materials. The tests were carried out according to standard PN-EN 1621-1, on the post constructed in the IAMM. The post's construction was close to the requirements of the Standard. The tests included measurement of the 'transmitted' force under the sample, after being hit with a 5 kg striker with 50 J kinetic energy.

According to the requirements of the standard, the average value of the force under the sample during such impact cannot exceed 35 kN, and no single value can exceed 50 kN. 20 different samples made from different materials were tested this way. Testing on the post allows the selection of materials which possess the required abilities of impact energy absorption.

User Tests

The prototype protective waistcoats with outer jacket were given to several riders for testing. According to the riders' opinion, the clothing ensures adequate comfort and ease of movement of the hands and torso, as well as easy access to fastenings and pockets. Different opinions on the evaluation of bolster collar resulted from the different angle of the rider during the ride, depending on the motorcycle type. During the ride on sport motorcycles, enforcing the rider's forward-leaning position, the riders complained that the collar was too close to the base of the neck; as a result, the collar pressed the helmet during the ride, and thus the helmet pressed the head and neck. The riders also experienced difficulties with free head rotation while looking sideways.

While riding tourist-class motorcycles, such as the Enduro type, the rider's position was upright, and such limitations were not noticed.

After initial operation tests, corrections to the collar's shape were introduced, allowing more freedom of head rotation. Also, regulation of the collar's base was introduced, to limit the pressure on the back of the head.

Summary

- Reports in foreign publications indicate that attempts to protect the brachial plexus during motorcycle traffic accidents have not been made.

- As a result of this research, criteria and design assumptions for protective clothing for motorcycle riders have been developed.
- Prototype specimens of waistcoats with integrated bolster collars were manufactured.

Conclusion

- The research constitutes a first step towards increasing motorcycle riders' safety by the application of special clothing.
- Recently, the clothing we developed has been introduced to industrial prototype production in LM SA, Trzebinia, Poland, a producer of protective clothing for use in extreme conditions; appropriate user tests should be planned and elaborated.
- Solving the problem of motorcycle riders' protection called for interdisciplinary collaboration between medical doctors, clothing specialists, experts in bio-mechanics, mechanics, metrology, polymer chemistry, composite materials, computer sciences and others, and should be continued.

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