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DYNAMIC MODEL DURING EMERGENCY MEDICAL TECHNICIANS LIFTING POSTURES

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Ⅰ. INTRODUCTION

Low back pain (LBP) is a widely known phenomenon in a wide variety of occupations, with the most often cited risk factor for LBP being work intensity. In particular, physically heavy work is usually associated with an increased risk of low back disorder. Pope, Andersson, Frymoyer, and Chaffin (1991) best described low back pain and its effect on industry as “the nemesis of medicine and the albatross of industry.”[1)]

One of the most hazardous activities often mentioned as a cause of occupational LBP in emergency medical technicians (EMTs) is handling patients. EMT's suffer injuries primarily during long backboard (LBB) lifting. These injuries include the back, wrist, shoulder, elbows, neck, hands, hip, and knees. Several factors affect these injuries including fast−paced movement, heavy lifting, repetitive lifting, and biomechanically disadvantageous body position.

The heath care industry is one of the most hazardous as far as back injury is concerned. In a comparative study of 24 occupational groups using annual incidence data from four US states, Jensen (1987) demonstrated that the rank order of the incidence ratios for back injuries paralleled the exposure to load handling[2)]. In this ranking four of the first seven in the largest back injury category were health care occupations.

Workplace ergonomic solutions can reduce RSIs, save companies money, and keep their work force to a minimum by reducing injuries, particularly in health care sector, which is EMTs field. Many EMTs suffer from musculoskeletal problems (Thieme−visser, 1980; van Blijwijk, 1986; Doormaal, Driessen, Landeweerd, and Drost 1995)[3,4,5)]. The main tasks of EMTs involve lifting patients from the ground onto a stretcher, moving patients on a chair stretcher, carrying patients downstairs in Rautek−grip, and moving patients in emergency situations. Patients are frequently lifted using a plastic LBB that is 200 cm long, 70 cm wide, and 5 cm tall.

As EMT's may be called upon to lift large

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patients (van Blijwijk, 1986 and Heerlen, 1990 have stated that up to 100 kg patients are not uncommon) appropriate protective lifting techniques have been developed[3,6]. Many researchers frequently describe two lifting techniques, the squat and stooped techniques. Actually, lifting techniques can be seen as a continuum. The two extremes of lifting techniques frequently discussed in the literature are leg lifting, where the knees are flexed and the trunk vertical; and back lifting, where the knees are straight and the trunk is flexed (Brown, 1972; Chaffin & Andersson, 1984; Kumar, 1984; Leskinen, Stalhammar, Kourinka, and Troup, 1983b; Troup, 1977)[7-11]. Based on cinematographic analysis of workers handling loads in a plant, Park and Chaffin (1974) reported that the values of compressive force at the L5/S1 disc were found to be much higher in the squat lifting technique than in the stooped lifting technique[12]. However, the values of shear force at the L5/S1 disc were found to be greater in the stooped lifting technique compared with the squat lifting technique. A third lifting technique, the lunge, has not received much attention in the lifting research. The lifter having one knee on the ground while the other knee is fully flexed characterizes the lunge technique.

Although researchers have studied several professions in the health care sector, the injuries sustained by EMTs have received little attention. In light of the vital role EMTs serve and the debilitating effect LBP has on this occupation, it is unfortunate that there are no studies for EMT's lifting the long backboard from the ground to an ambulance stretcher. Yet it has been hypothesized that complaints of LBP are the result of a biomechanical disadvantage associated with lifting patients from the ground to stretcher, due to in appropriate lifting techniques. In reality, EMT's in the field rarely use the lunge and squat lifting techniques. EMT's usually use the stooped and freestyle lifting techniques because EMT's have not been instructed in the proper lifting methods.

1. Purpose

Using proper body mechanics can help protect the back against injury. The purpose of this study is to develop a dynamic model of the lumbar spine to evaluate the compressive force, shear force, resultant force and muscle moment at the lumbar 4 and lumbar 5 (L4/L5) level with three different lifting techniques and three different load conditions. Furthermore, this study would enhance the understanding of the safe, effective, lifting motion patterns through biomechanical simulation of the LBB lifting techniques used by EMT's.

Ⅱ. METHODS

1. Subjects

Thirty-six male subjects volunteered to participate in this experiment. The subjects were not emergency medical technicians, and thus did not have prior experience lifting the long backboard. The subjects did, however, receive instructions on how to lift the long backboard. The average age was 21.42 (S.D = 2.74) years old, the average body height was 174.05 cm (S.D = 4.94), and the body mass was 78.05 kg (S.D = 3.45). Only volunteers without weight training experience were utilized. Subject pairs executed this experiment, in which the actual individual load condition was 50 kg, 70 kg, and 90 kg. The lifting height was 95 cm and the moment arm was 110 cm.

2. Experimental Procedure

The following instructions were given to ensure proper lifting technique. The subject was instructed to bend the knees and squat down, and to keep the back arched and the head up while lifting. The subject had worn the weight belt with a rigid. The subjects were further instructed that the legs, arms, and back should generate the lifting forces equally. Each technique sets the subject's toes on the edge of the long backboard (LBB). When lifting, the subject was instructed to keep objects close to the body. Prior to each experiment, all three lifting techniques (lunge, stooped, squat) were explained and demonstrated to each subject by the researcher.

3. Instrumentation

The equipment set up was provided as follows. Two-Dimensional (2-D) continuous recordings of the kinematics data were determined using the 2-D ProReflex Motion Capture Camera (60 Hz) developed by Qualisys, Inc. at Glastonbury, CT., 2-D kinematics data ProReflex Motion Capture Software with IBM 586. The camera was located 6 m perpendicular to the right side (sagittal plane) of the subject and filmed the last two completed lifting postures and load conditions. The focal axis was 1.0 m above floor level. A zoom lens was used to reduce parallax artifact and maximize the size of the subject image within the film frame.

4. Data Analysis and Reduction

The video analysis system automatically digitized the movements for kinematics data analysis. The X and Y coordinates of the markers were transferred to an IBM 586 DX computer for further processing. The raw data was used to construct seven segments, symmetrical, and link segment model (LBB - hand, hand - forearm, forearm - upper arm, upperarm - head, head - C7/T1, and C7/T1 - L4/L5). This study employed the dynamic model developed by McGill and Norman (1986) adapted to run in MATLAB[13].

The film data was smoothed to reduce automatic digitizing error and other noise (sources of error) during running the program. The raw data was first smoothed with the digital filtering technique, then the displacement, velocity, and acceleration of each segment was calculated. Kinematic data was determined from the smoothed data using linear interpolation.

The biomechanical properties of mass, center of mass, moment of inertia, and radius of gyration of the subject's body segments were derived from anthropometric measures in accordance with the descriptions from Winter (1991)[14].

A 'dynamic analysis' of the model was then conducted by determining the joint reaction

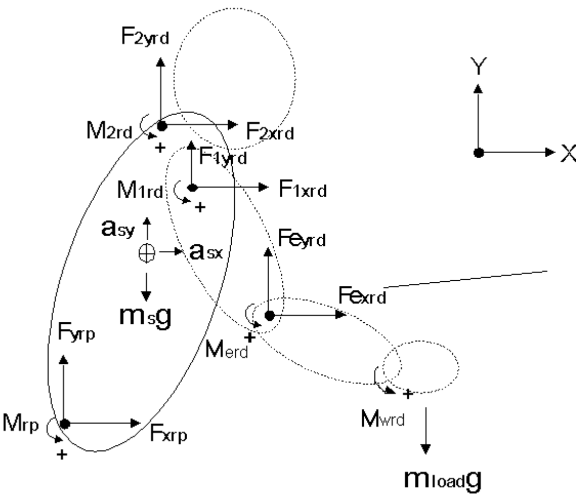

Figure 1. Dynamic Lifting Model (developed from McGill and Norman, 1986).

forces and net moments considering linear, angular velocity and accelerations of each segment. The mathematical representations (Figure 6) of the upper body were calculated by the computer program such as the external load, hand, elbow, shoulder, C7, T1, and L4/L5 joint reaction forces (X, Y direction) and net moments; L4/L5 disc compression, shear, and resultant forces. A cubic spline was used to interpolate kinetic data for calculation by an inverse dynamics model.

5. Dynamic Equation

$F1xrd = meaex - Fe\ xrd$

$F1yrd = meaey + meg - Fe\ yrd$

$M1rd = Ie - Merd + F1xrd\ Demay - F1yrd\ Demax$

$Fxrp = ms\ asx - F1xrd - F2xrd$

$Fyrp = ms\ asy + msg - F1yrd - F2yrd$

$Mrp = Is - M1rd - M2rd - Fxrp\ Pmay + Fyrp\ Pmax + F1xrd\ D1may - F1yrd\ D1max + F2xrd\ D2may - F2yrd\ D2max$

L4/L5 compressive force (Fc)

$Fc = Mrp / r + Fyrpcos + Fxrp\ sin$

L4/L5 Shear force (Fs)

$Fs = Fxrp\ (-sin) + Fyrpcos$

Resultant force $= (Fs2 * Fc2)\ 1/2$

6. Statistical Analysis

The acquired data was analyzed as a 3 (lifting techniques) by 3 (load) analysis of variance (ANOVA) within subject's design. It was conducted using 3 by 3 conditions by SPSS (SPSS/PC+ The Statistical Package for IBM PC) for windows. All tests were conducted at an alpha level of .05, including the post hoc test, scheffe'. The effects of three load conditions and three lifting techniques the measured parameters (compression force, shear force, and resultant force on the L4/L5, and trunk peakgles, moment, and anangular velocity and acceleration) were analyzed statistically using a two-way analysis of variance (ANOVA).

Ⅲ. RESULTS

The lumbar 4 and lumbar 5 (L4/L5) kinematics and kinetics characteristics were those variables obtained from the computer program simulation. The results of the analysis is as follow: Kinetics data: the maximum compression, shear, and resultant forces on the L4/L5.

1. Compressive Force

One may believe that if a back injury from anatomical and mechanical cause were to occur during lifting, the likelihood of its occurrence would depend upon the magnitude

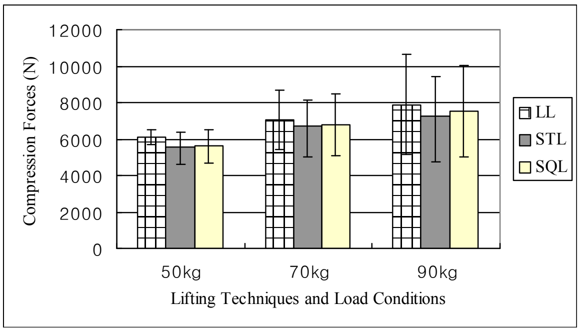

Figure 2. Mean Values of Maximum Compres- sion Force from the Three Lifting Techniques and the Three Load Conditions at the L4/L5.

of the compression force acting on the back during lifting. Therefore, the peak L4/L5 compression force would be an important factor.

Figure 2 demonstrates the mean compression forces on the L4/L5, which range from 5728.68 N (50 kg) to 7874.12 N (90 kg). The largest calculated compression forces in the 50 kg (6121.95 N), 70 kg (7049.37 N) and 90 kg (7874.12 N) load conditions occurs in the lunge lifting technique. The least compression forces occur during the stopped lifting technique in the 50 kg (5560.52 N), in the 70 kg (6688.79 N), and in the 90 kg (7282.17 N). The increases of load conditions were associated with significant increases in the maximum compression forces.

Figure 2 shows that at 50 kg, the lunge lifting technique generates (561.4 N) greater compression forces than squat lifting, and (525.0 N) greater compression forces than stooped lifting technique. At 90 kg, the lunge lifting technique produces (592.0 N) greater compression forces than squat lifting, and (334.4 N) greater compression forces than stooped lifting technique. In regard to compression forces, the lunge lifting technique produces a significantly ($p < 0.05$) greater compression forces than stooped and squat lifting techniques at loads of 50 and 90 kg.

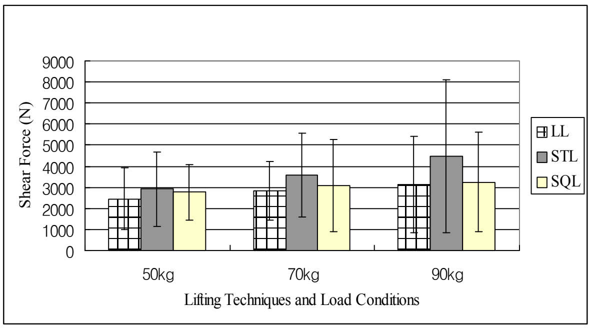

Figure 3. Mean Values of Maximum Shear Force from the Three Lifting Techniques and the Three Load Conditions at the L4/L5.

2. Shear Force

When lifting the Long Backboard (LBB) severity of a back injury from mechanical cause to occur would depend on the magnitude of the shear force acting on the back during lifting. The peak L4/L5 shear force would be a useful factor in understanding this risk of injury.

Figure 3 provides evidence that the load mass increases were associated with significant increases in the maximum shear forces on the L4/L5, which range from 2450.77 N (50 kg) to 4465.65 N (90 kg). Figure 3 presents the largest calculated shear forces in the 50 kg (2919.11 N), 70 kg (3598.58), and 90 kg (4465.65 N) for stooped lifting. The least forces were observed for lunge lifting technique in the 50 kg (2450.77 N), in the 70 kg (2824.86 N) and in the 90 kg (73137.81 N). Figure 3 shows that at 70 kg, the lunge lifting produces 773.7 N less shear force than stooped lifting and 520.9 N less than squat lifting techniques. At 90 kg, stooped lifting generates 1327.8 N shear forces greater than lunge lifting and 1211.0 N greater than squat lifting techniques. As expected, the subjects handling the heaviest loads also exhibited the largest shear forces. At 70 kg, the lunge lifting technique is significantly ($p < 0.05$) less in shear force than the stooped and squat lifting techniques with respect to the shear forces.

At the 90 kg load, the stooped lifting produces significantly ($p < 0.05$) greater shear force than lunge and squat lifting techniques (Figure 3). The lunge lifting technique generates less shear force than the other lifting techniques.

3. Resultant Force

One may believe that if a back injury from mechanical cause were to occur during lifting, the likihood of its occurrence would depend on the magnitude of the resultant force acting on the back during lifting. The resultant force needs to equilibrate the upper body force that is supplied in the lumbar trunk by muscle contractions, connective tissue tension, and resistances supplied by the L4/L5 motion segments. The resultant force is found using the vertical (y-axis) and horizontal (x-axis) vectors so that the x-axis and y-axis lie in the sagittal plane. The resultant force is equal to the square root of the sum of the compression force square and the shear force squared. The compression force is determined by adding the individual results, and the shear force is determined in the same way.

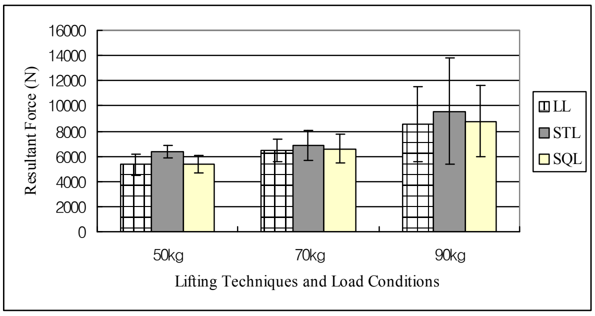

Figure 4. Mean Values of Resultant Force from the Three Lifting Techniques and the Three Load Conditions at the L4/L5.

There is a lack of resultant force findings with studies that employed film analysis. Therefore, the peak L4/L5 resultant force would be the most important injury factor. Figure 4 presents the mean values of maximum resultant force (extracted from film data) from the three lifting techniques and the three load conditions acting about the L4/L5 vertebral joint. The mean resultant forces on the L4/L5 range from 5701.95 N with 50 kg to 8950.52 N with 90 kg. The load increases are associated with significant increases in L4/L5 maximum resultant forces.

The largest calculated resultant forces occur during the stooped lifting technique (50 kg: 6368.83 N; 70 kg: 6823.33 N; and 90 kg: 9576.08 N). The least forces occur during the lunge lifting technique (50 kg: 5354.49 N; 70 kg: 6449.02 N; and 90 kg: 8521.04 N).

Figure 4 exhibits that at 50 kg, the stooped lifting technique produces 1014.3 N greater resultant forces than with lunge lifting and 994.7 N greater than squat lifting. At 90 kg, the stooped lifting technique generates 1055.04

N greater resultant forces than lunge lifting and 790.6 N greater than the squat lifting technique. The stooped lifting technique generates significantly ($p < 0.05$) greater resultant forces than the stooped and squat lifting techniques at the loads of 50 and 90 kg (Figure 4).

Ⅳ. SUMMARY AND SUGGESTIONS

1. Summary

One major finding of this study was that the largest calculated compression forces on the L4/L5 occurred during lunge lifting, the second greatest forces happened during squat lifting, and the least forces were observed during stooped lifting. This is an important finding because the compression forces produced were 1.0 times less than or greater than in previous studies and from 0.7 to 1.4 times greater or less than the maximum permissible limit of compression forces than the National Institute of Occupational Safety and Health Work Practices Guide (NIOSH or NIOSH WPG; 1981, 1983) considers safe15).

Another major finding of this study is that the stooped and squat lifting techniques caused considerably more shear stress on the L4/L5 disc than did the lunge lifting technique. The largest calculated shear forces were in the stooped lifting, the second greatest forces happened during squat lifting and the least forces were observed for lunge lifting. The shear force results from this study differ greatly from the least and largest values of previous studies, which varied from 2.5 to 12.3 times higher. Stooped lifting generated greater shear forces because of the greater magnitude and load, the greater length of the moment arm, and the wrecked equilibrium (asymmetrical lifting). This may be a factor in contributing to lower back pain while lifting heavy loads using the stooped lifting techniques. Park and Chaffin (1974) arrived at same conclusion with the stooped back lifting technique, which revealed more in erector spine muscle tension, as opposed to the leg technique due to a longer moment arm, which generated considerably more stress on the L4/L5 disc12).

The most unique finding of this study is that the largest calculated resultant forces occur during the stooped lifting technique. The second greatest forces occurred during squat lifting and the least forces occurred during the lunge lifting technique. This could imply that the traditional biomechanical parameters used for the ergonomic design of lifting tasks using resultant force might cause a higher incidence of low back pain associated with LBB motion.

The largest calculated moment in the load conditions occurs in the stooped lifting technique, and the least forces are observed in the condition utilizing the lunge lifting technique. However, the maximum moments were not significantly different between the three lifting techniques, as well as the three load conditions. The lunge lifting technique also decreased the L4/L5 bending moment suggesting that in order to reach further forward, it may be necessary to straighten the back and to raise the head to keep the center of gravity over the feet. At the other extreme, it is also possible to get too close to the load. The arm position might influence the lever arm of the load relative to the spine and consequently, the moment generated by lifting techniques.

2. Conclusion and suggestions

In conclusion, this study, which focuses on the compression forces, shear forces, resultant forces and muscle moment, reveals that the lunge lifting technique is least harmful to the L4/L5 vertebral joint. This decision is supported by the fact that the above–mentioned technique reduces the shear forces, muscle moment, and resultant forces. The lunge lifting technique, however, increases the compression force.

One may believe that if a back injury from anatomical and mechanical cause were to occur during lifting, the likelihood of its occurrence would depend upon the magnitude of the compression force and the shear force acting on the back during lifting. The research in this study could be interpreted that the great shear forces of the stooped lifting technique contribute to the injury of the facet joints. Great shear forces may, in particular, be a problem for EMT's who have pathological or anatomical abnormalities or changes of facets, since these provide the primary resistance to shear forces in the lumbar spine. Thus, it could be concluded that a minimization of the shear forces is beneficial even when compared with a similar increase in compression force. One could suggest that increased resultant forces present in asymmetric lifting motions may be a factor influencing the higher incidence of low back pain associated with the dynamic movement during the LBB lifting. The stooped lifting technique generated the largest amount of resultant forces in this study, and may be the least advisable. The squat lifting technique could be recommended also, because of the above reasons. The squat–lifting technique produced the median amount in all of the compression forces, shear forces, and resultant forces.

If compression forces were the primary concern of an EMT, the stooped lifting technique would be recommended. However, it is likely that compression forces are the least important, so the stooped lifting technique is not to be recommended. If shear and/or resultant forces were the primary concern, then the lunge–lifting technique would minimize both. Overall, the squat–lifting technique is recommended as the best technique for LBB lifting. This shows that the original hypothesis is not exactly correct.

These have implications in regard to lifting instructions given to improve EMT safety. Excessive acceleration and velocity of task performance and jerking of load should be avoided. On the basis of these results the following recommendations may be made: The lifting of the LBB from ground to the 95 cm high ambulance stretcher should be avoided by EMT's, instead using one third of ambulance stretcher. When lifting heavy weights with bent knees, initially one foot and knee should push on the ground, the hip should rise faster than the shoulder, and the trunk should finally be as erect as possible. Two EMTs should always try to count “One and Two” and lift the LBB simultaneously. EMTs could receive specific training in lifting techniques and should regularly pay attention to the matters of the most adequate techniques in specific situations, as well as stretching when EMTs resting.

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=국문요약=

응급구조사들의 들어 올리는 자세의 동역학적 모델 분석

신 동 민*

본 연구의 목적은 응급구조사들이 긴 척추고정판을 이용하여 환자를 들어 올리는 3가지 다른 자세와 다른 3가지 부하 조건을 이용하여, 요추 4번과 5번의 압축력, 전단응력 그리고 합력의 변화를 동역학적 모델을 제시하기 위한 분석이다.

연구방법 : 36명의 남자가 본 연구의 실험에 자발적으로 동원되었으며, 나이는 평균 21.42세이고, 신장은 평균 174.05 cm이며, 체중은 평균 78.05 kg이다. 이 실험에서 부하 조건은 50, 70, 90 kg이고, 들어 올리는 높이는 지상에서부터 95cm 이었으며, 들어 올리는 동안의 회전고리는 110 cm이었다. 운동현상학적 자료는 2-D ProReflex Motion Capture Camera을 이용하였으며, sampling rate는 60 Hz로 하였다.

결과 및 논의 : 동역학적 데이터 자료를 근거로 한 본 연구의 결론은 다음과 같다.

Lunge 자세기술에서 전단응력과 합력 등이 최소의 stress로 요추 4번 5번에 미치는 것으로 나타났다. 그러나 Lunge 기술에서 압축력은 약간 증가되는 것으로 나타났다. 이 연구에서 Stooped 자세기술에서는 아주 큰 전단응력과 합력 등이 요추 4번, 5번 관절에 넓게 작용하는 것으로 나타났으며, 이는 들어 올리는 동작을 할 때 상해의 원인이 된다고 사료된다. 특히 응급구조사들이 들것을 들어 올릴 때 너무 큰 전단응력이 요추 4번, 5번 관절에 작용을 하면 비정상적으로 병리학상 또는 해부학상 신체적변화가 온다고 해석할 수 있다. 그래서 응급구조사들에게 들것을 들어올리는 stooped 자세는 아주 크고 많은 합력 작용하기 때문에 권고될만한 기술이 아니라고 해석 된다. Squat 자세에서 중간 정도의 압축력, 전단응력 그리고 합력이 작용된다. 만약 응급구조사가 전단응력 그리고 합력이 요추에 미치는 영향이 가장 걱정된다면, lunge 자세가 두 가지 힘을 줄여줄 수 있다고 사료된다. 마지막으로 응급구조사가 들것을 들어올리는 데는 squat 자세 기술이 가장 좋다고 사료 된다.

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