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An ergonomic analysis and computer simulations of nursing activities while raising the patients in hospitals and nursing homes

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ABSTRACT

Background: The use of trolleys for transporting the patients and lifting and lowering them in the trolley is a repeated activity in the daily work of a nurse, and a very common cause of the load of the lumbosacral part of the spine and the consequent pathological deformity, and the onset of clinical symptomatology of painful lumbo-sacral syndrome. The high level of excessive biomechanical stress is associated with the established practice of using standard medical wheelchairs to move patients inside the hospital. The process itself depends on the characteristics of the patient, his or her weight, as well as his/her cooperativeness, but primarily depends on the nurse's mobility. Although nurses strive to be in a position that reduces the load on the lumbosacral part of the spine during practice, this is often impracticable due to the patient's inconsistency.

Objective: To present the ergonomic analysis of the medical nurse's workplace while lifting the patient into the wheelchair and to display solution for improving working conditions and prevention of musculoskeletal disorders.

Results: By ergonomic module of this software, we got results that present load on lumbosacral region of spine of medical nurses during their daily activities, especially in the position of lifting and lowering patients. It was concluded that maximal spinal loading decreases significantly and becomes less than critical (3,100 N) in the case of a wheelchair that has ability to automatically lift and lower patient.

Conclusions: The use of hospital wheelchairs with an mechanism for the automatic lifting and lowering of patients and with a sliding seat will reduce the load on the lumbosacral region of the spine, prevent the onset of lumbosacral pain syndrome, facilitates work for the medical nurse and allows nurse to handle the patient on her own. The prevention of lumbosacral pain syndrome improves the quality of work of the nurse and extends the working life. Use of this type of wheelchair is justified in terms of cost-benefit analysis.

Keywords: Low back pain, Ergonomics, Software Tools

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1. Introduction

Occupational diseases present one of the greatest problems of modern medicine. They are defined as diseases that have arisen or worsened due to working conditions (1). The development of the term "occupational health" has led to the promptly identification and prevention of exposure to the cause of the disease (2). The etiological factors for this disease are physical, chemical and biological (3).
Occupational diseases in medical professionals have been researched on studies that have shown the importance of radiation exposure prevention or prevention of contact with infectious matter, and success has been achieved in this field (3,4). More recently, the focus has also been on exposure to stress, the impact of night shift work, as well as contact with various types of violence, which further complicates the mental status of the health care provider (4). A particular entity is the clinical symptoms that impair the health of the healthcare provider which are related to the daily activities that are part of healthcare provider job description (4). Primarily, pain in the musculoskeletal system has become something that the medical professional lives

with, and something that is not pay attention on, till the moment when daily activities of the healthcare worker can not be done (4,5,6).
Masoudi et al. stated in their research that as 89% of nurses have pain in the musculoskeletal region, while 74% of them have low back pain (4). Engels et al. reported that 57% of nurses in the Netherlands have musculoskeletal pain (a total of 890 nurses have been analyzed) (7). Souza et al. showed that 80.7% of nurses have pain in the musculoskeletal system in a sample of 301 nurses (6). Tinubu et al. report that 78% of nurses in Nigeria have pain symptoms associated with the musculoskeletal system, while Yan and et al. estimate that this number is 77.4% in the Chinese population (8.9).
Although the onset of pain itself does not present disability to work, the fact is that repetition of these actions that cause pain during the time, lead to musculoskeletal deformities and various forms of pathological conditions, which will result with disability to perform a specific activity. Of all healthcare workers, the population of medical nurses is considered to be the most vulnerable, although this depends on the type of work but also on field and ward in which the nurse works (9,10,11,12).
All of the above leads to the conclusion that this is a universal problem. It is more noticeable in less developed healthcare systems due to work overload and more health services included in the job description of a nurse. The job description of nurses is patient care and jobs in the form of lifting heavy patients, pushing heavy equipment, moving patients or holding heavy instruments in operating rooms. There are appropriate ergonomic solutions in the form of different types of chairs and various devices that reduce the load on the spinal column, but that is not something what is still established in daily practice due to many reasons.
The assessment of the risk of different pathology in these type of job includes consideration of: the physical complexity of the job (force required, awkward body position, frequency and duration of work), patient characteristics (height, weight, cooperativeness), work environment (infrastructure) and work organization (work in shifts, number of staff) (10,11,12,13).
Although all this depends on many factors, primarily the organization of work and the health system infrastructure, the fact is that in modern medicine, the focus must be on the prevention of musculoskeletal disorders, which will ultimately lead to benefits for the employer himself, but also enable better quality of work. With all of the above, the physiological changes in the musculoskeletal system that accompany females (still the majority of nurses are females) further complicate this problem (13,14,15). Workplace optimization is an imperative.
The use of chairs for transporting the patient and lifting the patient into the chair is a repeated activity in the daily work of a medical nurse. It is vey common cause of the lumbosacral load and the consequent pathological deformity (it is first cause of clinical symptomatology of lumbosacral syndrome). The high level of excessive biomechanical stress on spinal column is associated with the established practice of using standard hospital chairs to move patients inside the hospital. The process itself depends on the characteristics of the patient, his or her weight, as well on his / her cooperativeness, but primarily depends on the nurse's manual skills. Although in practice nurses strive to be in a position that even reduces the load on the lumbosacral part of the spine, it is often impossible to achieve because of the patient's non- cooperativeness.

2. Aim

To present the ergonomic analysis of the medical nurse's workplace while lifting the patient into the wheelchair and to display solution for improving working conditions and prevention of musculoskeletal disorders.

3. Methods

The article has an analytical character. Analysis has been done in the CATIA software package (Dassault Systèmes, Vélizy-Villacoublay, France). The RULA Assessment Tool was used in the processing of data (score 1-2 -green color - negligible risk, no action required; score 3-4 - light yellow - low risk, change may be needed; score 5-6 - yellow - medium risk, change soon; score> 6 - red color - very high risk, implement change needed.

4. Results

In order to analyze the load in the lumbar region during raising and lowering the patient, a nurse model of body weight 62 kg, height 170 cm and 30 years of age was created (Fig. 1). A patient that is lifted from the wheelchair of 50 cm in height was modeled to be 70 kg of body weight, as shown in Fig. 2.

4.1 First body position

Using the *'Biomechanic single action analysis'* function of the CATIA software, a biomechanical load and RULA analysis for this position was performed.
The compression of the L4/L5 was 10,720 N, which is far above the allowed maximum value of 3,400 N. The abdominal force was 85 N/m^2 and the abdominal pressure was 3 (Fig. 3).

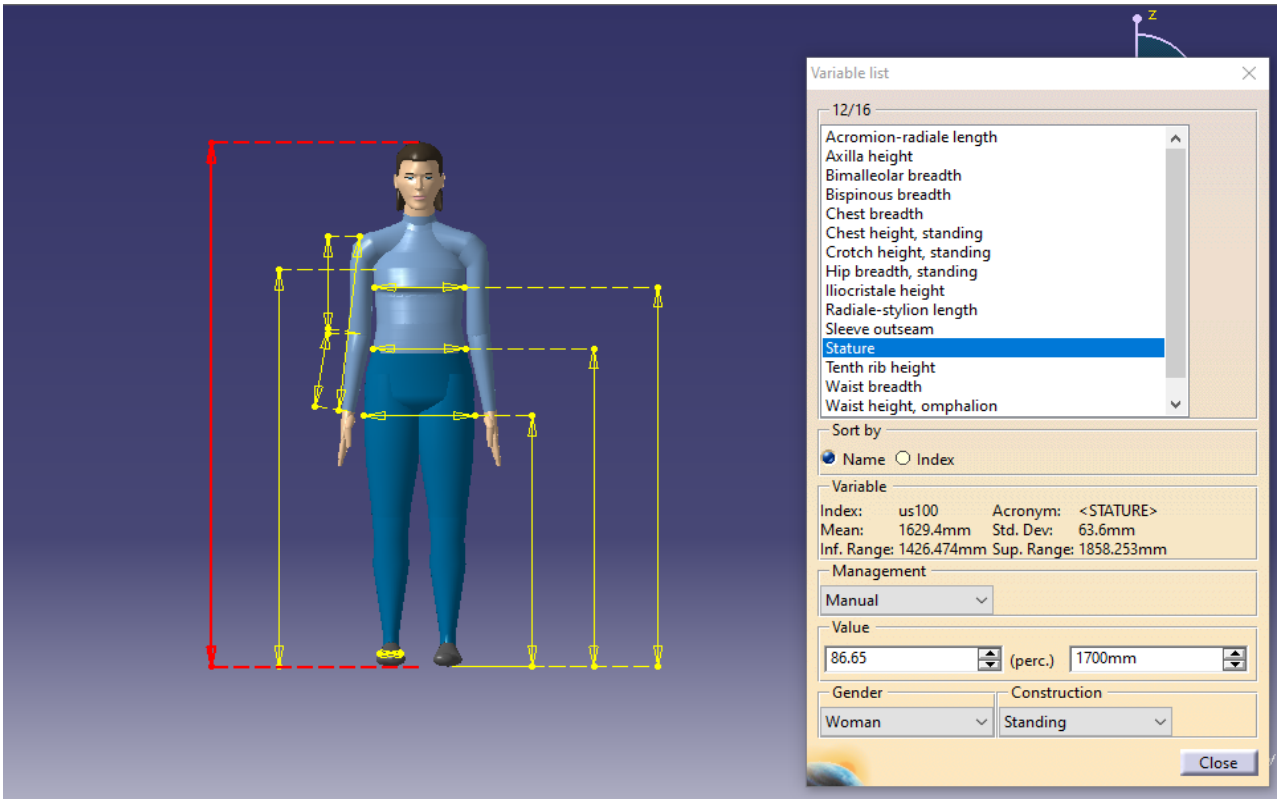

Figure 1. CATIA computer model of the medical nurse

Figure 2. First body position

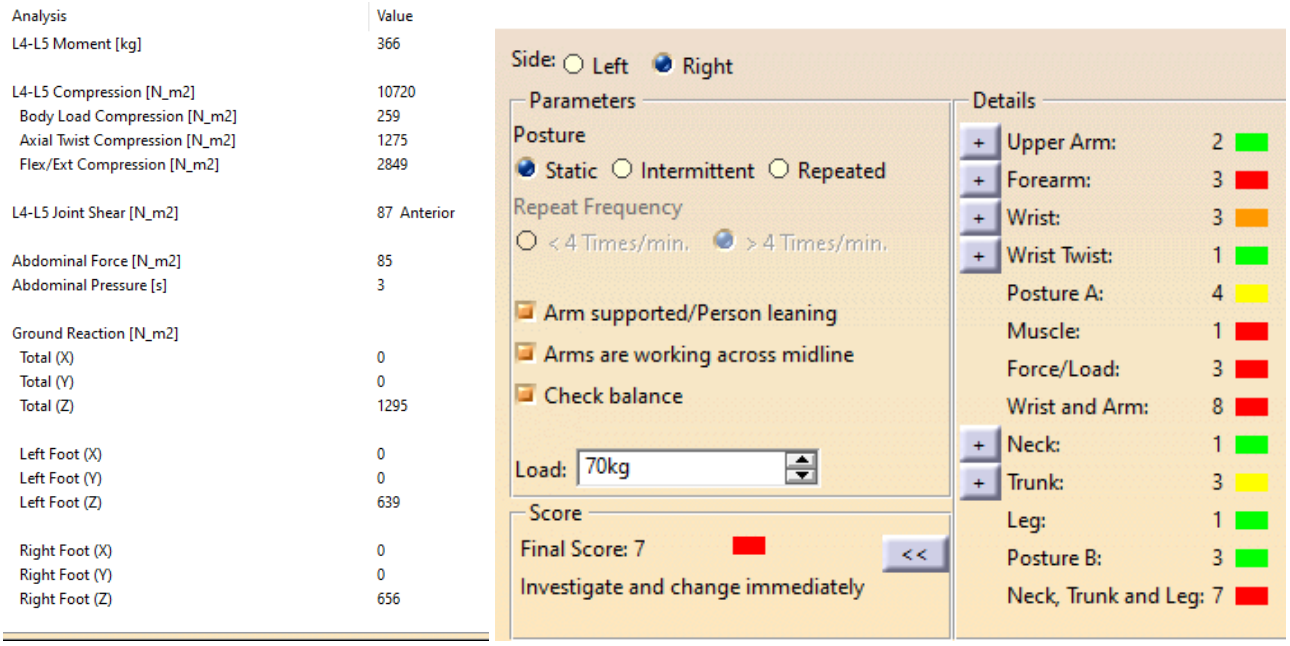

Figure 3. Biomechanical and RULA analysis of the first body position

As it can be seen from Fig. 3, the final result of the RULA analysis for a given position is 7 (red color), which means that the analyzed position has a significant impact on the nurse's health and is extremely unfavorable.

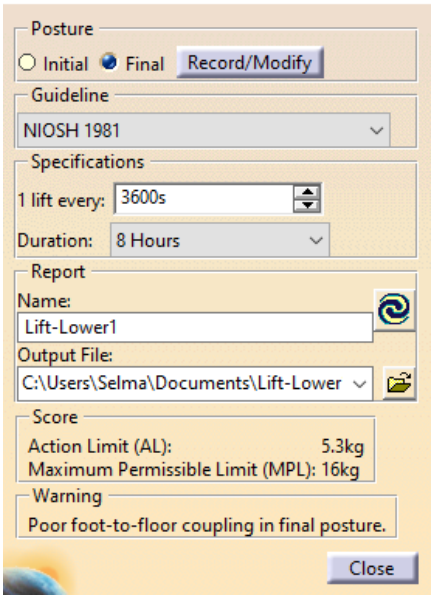

Figure 4. NIOSH 1981 analysis of the first body position

The results of the NIOSH 1981 analysis for the above input data (lifting a patient weighing 70 kg every hour during the day) show that this position of the nurse, as well as the given weight of the patient, greatly risk a deterioration in the health status of the nurse, with warning '*Poor foot-to-floor coupling in final posture*'.

4.2 Second body position

Second body position corresponds to the situation in which the nurse has raised the patient and is in her vertical position (Fig. 5). The biomechanical and RULA analysis was performed for this position (as shown in Fig. 6), finding that the compression force was 8,823 N. This is a significant decrease over the compression force value from the previous case, but still does not meet the allowable load values in the L4/L5 zone. The abdominal force and pressure in this position are 0.

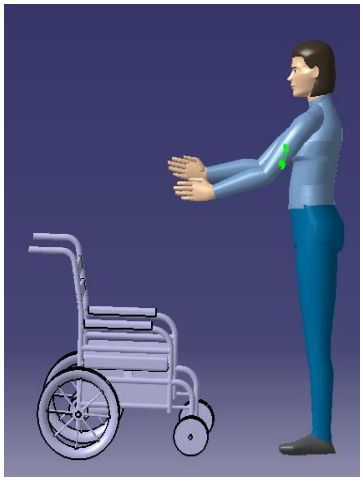

Figure 5. Second body position

Analysis	Value
L4-L5 Moment [Nxm]	147
L4-L5 Compression [N]	8823
Body Load Compression [N]	409
Axial Twist Compression [N]	988
Flex/Ext Compression [N]	1612
L4-L5 Joint Shear [N]	27 Posterior
Abdominal Force [N]	0
Abdominal Pressure [N_m2]	0
Ground Reaction [N]	
Total (X)	0
Total (Y)	0
Total (Z)	1295
Left Foot (X)	0
Left Foot (Y)	0
Left Foot (Z)	408

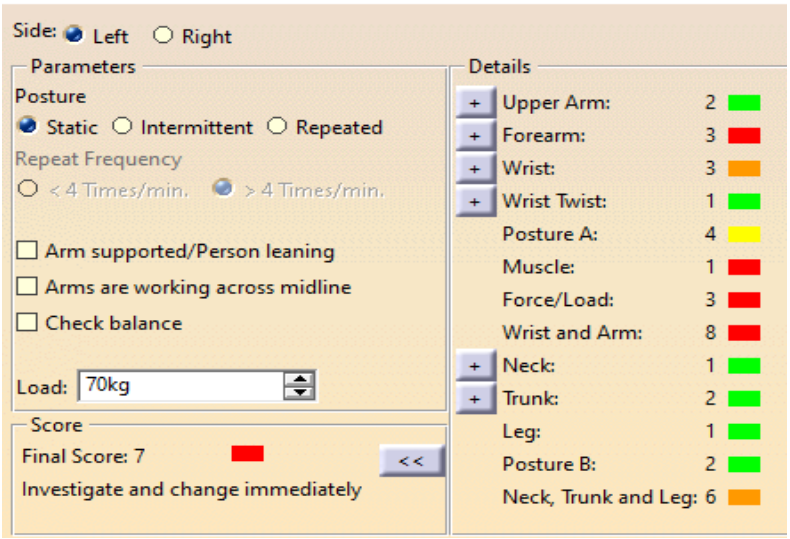

Figure 6. Biomechanical and RULA analysis of the second body position

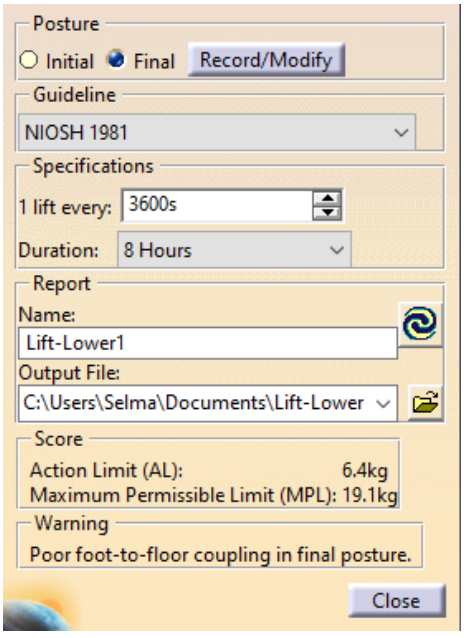

Figure 7. NIOSH 1981 analysis of the second body position

We note that the result of NIOSH analysis is still unfavorable to the nurse, with warning '*Poor foot-to-floor coupling in final posture*'.

4.2 Position 3 - two nurses employed

The results of the analysis for both positions indicate that the stated conditions, that is the use of standard hospital trolleys for the transportation of patients, are inadequate for the single nurse in charge of the patient. The situation can be somewhat remedied by hiring two nurses to raise and lower the patients from a wheelchair instead of one. However, biomechanical and RULA analysis shows that the maximum allowable load values in the L4/L5 zone are exceeded in this case as well, although it is now 6,130 N for each nurse individually (Fig. 8).

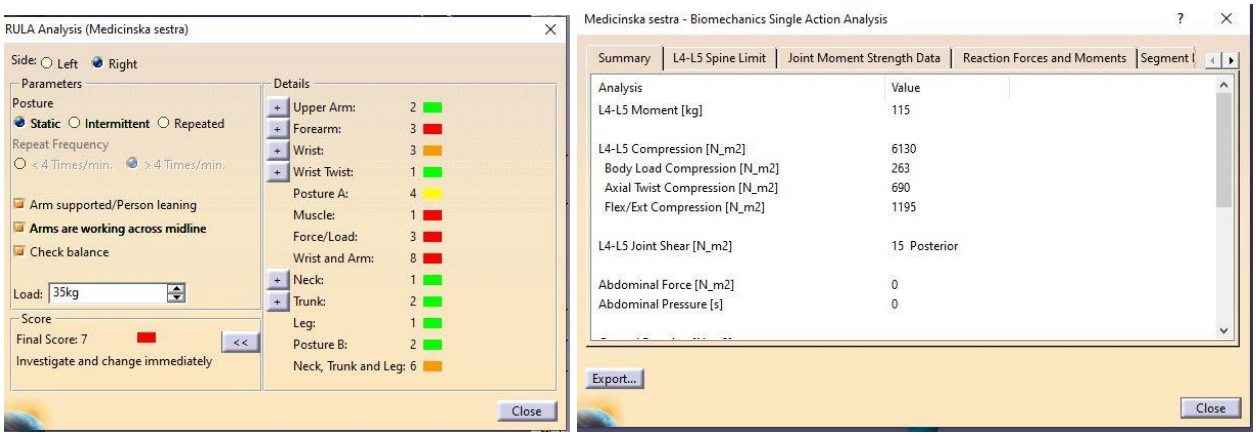

Figure 8. Biomechanical and RULA analysis for the case when two nurses are hired for one patient

5. Sliding hospital wheelchair with hydraulic mechanism

Given that the previous analysis found that the use of standard hospital wheelchairs for the transportation of patients was inadequate and unfavorable to the health of medical staff, an appropriate alternative solution had to be found. One possibility is to use more advanced hospital wheelchairs with a hydraulic mechanism that can automatically raise and lower patients, like the one from Fig. 9. This particular wheelchair design has an adjustable height with a sliding seat that is very useful for the caregiver as well as the care recipient. Designed according to universal design principles, sliding hospital trolleys have a seat that automatically raises to rise to the height of the bed in which the patient lies. The seat also moves sideways to maximize the comfort with which the patient crosses out of bed and then automatically lowers him/her down to a height suitable for further transportation.

Figure 9. Optimized hospital trolleys with a hydraulic moving mechanism

6. Calculation of energy used to transport patients

Work spent on raising a patient from the wheelchair can be expressed as the product of the force in the hands and the height of the lift. The force in the hands is calculated as the aggregate force that loads both hands and

is calculated based on the mass of the load the nurse is lifting and the gravitational acceleration:

$$F = m * g = 70 \cdot 9.81 = 686.7 \text{ [N]} \quad (1)$$

or, if take into account the the coefficient of friction of the nurse's skin arm:

$$F = m * g * \mu = 70 \cdot 9.81 * 1.0 = 686.7 \text{ [J]} \quad (2)$$

where μ - is the coefficient of friction of the nurse's skin arm, with the indicative value of 0.6 – 1.0.

The work done here is given by the lifting force multiplied by the distance traveled:

$$A = F * s = 686.7 \cdot 1.2 = 824.0 \text{ [J]} \quad (3)$$

Power consumed during one work shift is calculated by expression:

$$E = A * f * P * \theta = 824.0 \cdot 0.1 * 8 * 2 = 1{,}318.5 \text{ [J/WC]} \quad (4)$$

where:

A - is a total load lifting job,
f - is the frequency of repeating activity per minute,
P - is the period of activity,
Θ - is the fatigue factor, which depends on the frequency and mass of the load being carried,
WC - is the duty cycle, which is in this case 8h = 480min.

The fatigue factor Θ moves within the following limits:

1.1 - easy jobs and
2.0 - heavy jobs.

6.1 BMR energy calculation

The amount of energy required for the organism to function (breathing, organ function, digestion, metabolism, etc.), comonnly know as Base Metabolic Rate (BMR), can be estimated approximately using ergonomic formulas, the most commonly used *Harris - Benedict* formula:

$$BMR_{female} = 65.51 + (9{,}563 \cdot M) + (1{,}85 \cdot H) - (4{,}676 \cdot Y) \quad \text{[kcal/day]} \quad (5)$$

where M is the mass and H the height of the person. In the case of a time interval of 8 hours, the above formula gives a value of

$$BMR_{female} = 832.6 \text{ [kcal/day]} = 3{,}480.4 \text{ [J/day]} = 1{,}160.1 \text{ [J/WC]} \quad (6)$$

The total power consumption in the duty cycle represents the sum of the BMR and the power consumed during the shift:

$$E_t = E + BMR = 1{,}318.5 + 1{,}160.1 = 2{,}478.6 \text{ [J/WC]} \quad (7)$$

The energy needs to offset previously consumed energy can be calculated using the following formula:

$$E_{needs} = BMI \cdot 24 \cdot faf \text{ [kcal]} \quad (8)$$

where *BMI* is Body Mass Index and *faf* is Physical Activity Factor. Body Mass Index can be calculated using the *Lorentz formula*, witch for our model gives BMI_{female} = 62 [kg]. This means that the optimal body weight for this work position is 62 kg. The energy needs is calculated using this value.

Physical Activity Factor can be determined using the values from the Table 1.

Table 1. Physical Activity Factor determination

Gender	Easy physical activity	Moderate physical activity	Heavy physical activity
Male	1.55	1.78	2.10
Female	1.56	1.64	1.82

so, we finally get

$$E_{needs} = 62 \cdot 24 \cdot 2.10 = 3{,}125 \text{ [kcal]} \quad (9)$$

The average energy value during the week (with three work shifts per day) is $E_{needs}/3 = 1{,}041.7$ [kcal]

Based on above value it can be suggested an appropriate five-day menu with total calorie value that compensates spent energy, as shown in Table 2.

Table 2. Suggested menu (Kcal - kilocalories, l – liters, ml - milliliters, g-grams)

Day in week	Food name	Groceries					Total [kcal]
Monday	Chicken and green beans	chicken meat	green beans	chocolate	bread	orange juice	955
		200 [g]	100 [g]	30 [g]	100 [g]	0.5 [l]	
		250 [kcal]	100 [kcal]	140 [kcal]	250 [kcal]	215 [kcal]	
5% increase because of the added fat and spices: **974.0**							
Tuesday	Young beef and peas	beef	peas	cake	bread	orange juice	960
		250 [g]	250 [g]	50 [g]	100 [g]	0.2 [l]	
		350 [kcal]	350 [kcal]	150 [kcal]	200 [kcal]	100 [kcal]	
5% increase because of the added fat and spices: **1,008.0**							
Wednesday	Pasta with meat	meat	pasta	cake	peanuts	lemon juice	920
		150 [g]	200 [g]	50 [g]	10 [g]	0.3 [l]	
		250 [kcal]	250 [kcal]	200 [kcal]	50 [kcal]	170 [kcal]	
5% increase because of the added fat and spices: **1,203.33**							
Thursday	Tuna and corn	tuna in oil	corn	plasma cake	bread	orange juice	1024
		100 [g]	100 [g]	50 [g]	100 [g]	0.3 [l]	
		300 [kcal]	144 [kcal]	210 [kcal]	200 [kcal]	170 [kcal]	
5% increase because of the added fat and spices: **1,262.17**							
Friday	Beef with potatoes	beef	potatoes	chocolate cake	bread	orange juice	900
		150 [g]	100 [g]	50 [g]	100 [g]	0.3 [l]	
		250 [kcal]	100 [kcal]	200 [kcal]	180 [kcal]	170 [kcal]	
5% increase because of the added fat and spices: **1,260.02**							

7. Discussion

The workplace, along with family and school, is one of the three primary social communities and present one of the most important social determinants of health. A healthy workplace environment is a mandatory for social, mental and physical health, and a healthy working person is a prerequisite for social survival.

By improving workplace health, employees are more productive. This process will increase employee satisfaction, reduce rates of absenteeism, reduce incidence of early retirement and increase economic profits. Promoting the use of healthier technologies in work processes will protect health of worker, but also affects the progress of society (16). Nurses most often deals with diseases of the musculoskeletal system, and they are population with highest incidence of clinical symptoms of the lumbosacral part of the spine, primarily because of a job description (due to patient handling, positioning, lifting, bed making in extremely awkward postures, transferring to bed, wheelchair, toilet, for diagnostics and therapy) (17).

Our analysis showed that for the most common position when lifting patients out of the classic wheelchair is destructive for the lumbosacral region of the spine. The compression force on L4/L5 is 10,720 N, which is nearly three times more then force that is physiological and allowed. Lifting the patient in a vertical position also loads the lumbosacral region of the spine, although the position is more natural, but the force is still 8,823 N, what is 2.5 higher than normal values. If another medical nurse is involved in the same job, the workload will again be twice higher then physiological, with the loss of work efficiency. All of the above resulted with a solution that would allow better quality of work, but also preserve the health of the nurse. Our solution is to use hospital wheelchair with an mechanism for automatic lifting and lowering of patients, with

the use of sliding seat, which would allow adjusting the height of wheelchair, and by that reducing the load on the lumbosacral region of the spine. This will prevent pathological changes of the spinal column. Sliding wheelchairs are ideal for people who are under special care and have difficulty moving from their bed in a wheelchair. Wheelchair design has an adjustable height with a sliding seat that
will make easier to lift and lower the patient according to the patient profile. This design has proven to be very useful for the caregiver as well as the care recipient.
The load on the lower lumbar part of the medical staff is minimal because the most of the work is taken by the wheelchair mechanism. Investing in the development of such a system increases the efficiency of job and significantly reduces the overall cost.
Optimizing working conditions for the nurse's work requires adequate nutrition plan.
Calorie needs were obtained by calculating the energy needed for daily activities. This is another step that would lead to better quality of work, and certainly has and effect to overall health status of the nursing population. Adequate nutrition and optimization of the nutrition plan would satisfy both, physical and mental health, and certainly increase the quality of work activities. It should be emphasized that the concept of health development has many similarities to economic development. Both of these processes are result of activities which involving many sectors of society, as well as the population as a whole, through individual and collective decisions and actions. Investing in infrastructure renewal is essential and leads to the development of the organization itself as well as the development of the individuals. The quality of the work itself is raised through an adequate organization, that is, the allocation of responsibilities, tasks and resources (personnel, equipment, money, facilities and information) in order to provide quality health services (18). Health is not only the absence of illness, it is a state of complete physical, mental, spiritual and social well-being, and this should also be the focus of the employer in order to improve the quality of the work.

8. Conclusions

The use of hospital wheelchairs with an mechanism for the automatic lifting and lowering of patients and with a sliding seat will reduce the load on the lumbosacral region of the spine, prevent the onset of lumbosacral pain syndrome, facilitates work for the medical nurse and allows nurse to handle the patient on her own. The prevention of lumbosacral pain syndrome improves the quality of work of the nurse and extends the working life. Use of this type of wheelchair is justified in terms of cost-benefit analysis.

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