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Flexed lumbar spine postures are associated with greater strength and efficiency than lordotic postures during a maximal lift in pain-free individuals

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ABSTRACT

Background: Inspite of common lifting advice to maintain a lordotic posture, there is debate regarding optimal lumbar spine posture during lifting. To date, the influence of lumbar posture on trunk muscle recruitment, strength and efficiency during high intensity lifting has not been fully explored.

Research question: How do differences in lumbar posture influence trunk extensor strength (moment), trunk muscle activity, and neuromuscular efficiency during maximal lifting?

Methods: Twenty-six healthy participants adopted three lumbar postures (maximal extension (lordotic), mid-range (flat-back), and fully flexed) in a free lifting position. Motion analysis and force measurements were used to determine the back extensor, hip and knee moments. Surface electromyography (EMG) of three trunk extensors and the internal obliques were recorded. Neuromuscular efficiency (NME) was expressed as a ratio of normalised extensor moment to normalised EMG.

Results: Significantly higher back extensor moments were exerted when moving from an extended to mid-range, and from a mid-range to fully flexed lumbar posture. This was accompanied by a decrease in activity across all three back extensor muscles ($P < 0.001$) resulting in a higher NME of these muscles in more flexed postures. Change in lumbar posture did not influence hip or knee moments or internal oblique activation.

Significance: A flexed-back posture is associated with increased strength and efficiency of the back muscles compared to a lordotic posture. These findings further question the manual handling advice to lift with a lordotic lumbar spine.

1. Introduction

Low back pain is the leading cause of disability in the world [1], and lifting is one of the known risk factors for LBP in manual workers [2]. Clinicians and manual handling advisors commonly recommend lifting with a "straight" or extended, rather than a flexed lumbar spine [3,4]. However this practice has been recently questioned due to a lack of *in vivo* research demonstrating a clear relationship between a flexed lumbar spine when lifting and low back pain [5]. Furthermore, manual handling interventions advising people to minimise lumbar flexion when lifting have failed to reduce the incidence of LBP [6]. Indeed people with and without LBP, and physiotherapists report being fearful of lifting with a flexed lumbar spine [7]. Together this highlights the uncertainty regarding current lifting advice.

Lumbar posture has been shown to influence trunk muscle activation, although observations appear conflicting. For example, during maximal trunk exertions Nordin et al. [8] and Roy et al. [9] showed increased erector spinae (ES) activation and NME when moving from upright standing to a flexed lumbar posture, whereas Marras et al. [10] found muscle activity decreased. A potential limitation of these studies is that they only measured muscle activity of the lower erector spinae (LES), which neglects the complex functional role played by the different paravertebral (e.g. upper erector spinae (UES); LES; and multifidus) and abdominal muscles of the lumbar spine during functional lifting activities [8,9,11–13].

Considering the limitations of previous studies, this study

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investigated the influence of lumbar posture on trunk muscle recruitment, strength and neuromuscular efficiency during high intensity lifting.

2. Methods

2.1. Design

An experimental, repeated measures study design was undertaken to investigate the effects of three lumbar postures (fully flexed, mid-range and maximal extension) during maximal voluntary isometric force exertions in a symmetrical lifting posture. The muscle activity of three paravertebral (UES, LES and multifidus) and one abdominal (internal oblique (IO)) muscle was measured when performing maximal trunk extension in a lifting position.

2.2. Participants

Thirteen males and 13 females participated in the study. Their demographic data are presented in Table 1. Participants were excluded from the study if they: presented with a history of low back pain (LBP) in the previous 12 months; had undergone previous spinal or abdominal surgery; or had a neurological or rheumatological condition; or were pregnant. All participants gave written informed consent and the study was approved by Auckland University of Technology Ethics Committee (AUTEC).

2.3. Experimental procedure

Participants were required to perform a maximum isometric trunk extension while adopting a symmetrical lifting posture, with their knees flexed to 45°. Initially, trunk inclination was determined by instructing participants to reach down to pick up a box with handles that were 35 cm above the floor. The box was removed during isometric back extensions trials. Movement of the trunk was restrained using a chain attached to a chest harness located at the level of the sixth thoracic vertebrae and a floor mounted three-dimensional (3D) force gauge (Advanced Mechanical Technology Inc., Watertown, USA). While maintaining the same knee position, participants adopted three lumbar spine postures: 1) fully flexed (flexed); 2) a posture midway between maximum flexion and extension (mid-range); and 3) maximal extension (arch) (Fig. 1).

The order of force exertions were randomly allocated to the lumbar postures. In the lifting position, participants gradually increased trunk extensor force over two seconds and maintained a steady, maximum force for a further three seconds. Participants were not trained in performing the lifting task or provided with instructions about the trunk muscle recruitment strategy they should adopt prior to or during the maximal exertion. Maximum exertions were repeated three times for each condition, with the highest peak force used in subsequent analysis.

2.4. Lumbar posture

Lumbar angle was measured using an electromagnetic motion tracking system (Fastrak Polhemus Navigation, Kaiser Aerospace Inc., Vermont USA). In the standing position, motion sensors were secured to the skin superficial to the L1 and S1 spinous processes using doubled sided adhesive tape. Lumbar angle in the sagittal plane was defined as the difference in the relative angle between L1 and S1 [14]. Total range of lumbar spine motion was the difference in measured lumbar angle between upright standing and full flexion [15].

Lumbar posture data were sampled at a frequency of 30 Hz using LabVIEW software (National Instruments, Austin, USA, version 14.0), with participants able to view a graphical representation of lumbar curvature in real-time on a computer screen positioned directly in their line of sight.

Table 1
Participant mean (standard deviation) demographic data.

	Male (n = 13)	Female (n = 13)	Combined (n = 26)
Age (yr)	24.2 (4.6)	22.6 (5.2)	23.4 (4.9)
Weight (kg)	78.5 (8.8)	64.4 (13.5)	71.4 (11.2)
Height (m)	1.77 (0.1)	1.64 (0.1)	1.70 (0.1)

2.5. Kinematic and kinetic measures

A nine-camera motion analysis system (Qualysis Medical AB, Sweden) sampling at 60 Hz recorded 3D kinematics. Thirty-one lightweight, retro-reflective makers (9 mm diameter) were attached to the skin of participants and harness to record the position of the trunk, pelvis and lower limbs. Markers attached to anatomical landmarks defined the dimension and axis of each body segment [16].

During maximum back exertions, participants were required to stand with one foot on two separate force plates (Advanced Medical Technology Inc., Watertown, USA). 3D ground reaction forces were sampled at 1200 Hz to provide a measure of the forces acting independently through each foot. Raw kinematic and kinetic data were smoothed using a Butterworth low-pass recursive filter with a cut-off frequency of 6 Hz and 12 Hz, respectively.

2.6. Biomechanical modelling

The extensor moment (EMz) acting at the distal end of the trunk (external moment) was determined for all conditions. This was estimated in the sagittal plane based on the method proposed by Dolan & Adams [14] (Fig. 2).

The extensor moment of the trunk (EMz) was calculated such that:

$$EM_Z = F_R\, X_1 + T_Y\, X_2 + UB_Y\, X_3$$

where:

F_R = Resultant force acting on the trunk
T_Y = Trunk mass
UB_Y = Upper body mass (head, neck, arms and hands)
X_{1-3} = Moment arm for each force vector about the trunk origin

The origin of the trunk was located distal to the trunk and 7.5 cm anterior to the tip of the L5 spinous process [14], perpendicular to the long axis of the trunk. The mass of the trunk and upper body (head, neck, arms and hands) was estimated as a function of body weight (0.355*body weight (BW) and 0.181*BW, respectively). The centre of mass of the trunk and upper body was positioned along the long axis of the trunk, distal to the first thoracic (T1) spinous process (0.5*trunk length (TL) and 0.374*TL, respectively) [16–18].

Inverse dynamics was used to estimate joint reaction forces and net moments (internal moments) about the knees and hips. This used an eight segment, rigid-link dynamic biomechanical model of the pelvis and right and left lower limbs (thigh, shank and foot). The mass, centre of mass and inertial properties of each segment were estimated based on the regression equations of Dempster [17] and Winter [18]. All biomechanical modelling was conducted using Visual 3D biomechanics software (C-Motion Inc, Germantown, USA, version 4).

2.7. Electromyography

Surface electromyography (EMG) was used to record muscle activity from the right UES at the level of T10, the LES at the level of L3/4, and the multifidus at the level of L5, and IO (midway between the anterior superior iliac spine and symphysis pubis, superior to the inguinal ligament) [19]. Bi-polar surface electrodes (Norotrode 20 T M, Myotronics, Inc, WA, USA) with a separation of 10 mm were attached to the shaved skin surface at each location in accordance with the SENIAM guidelines

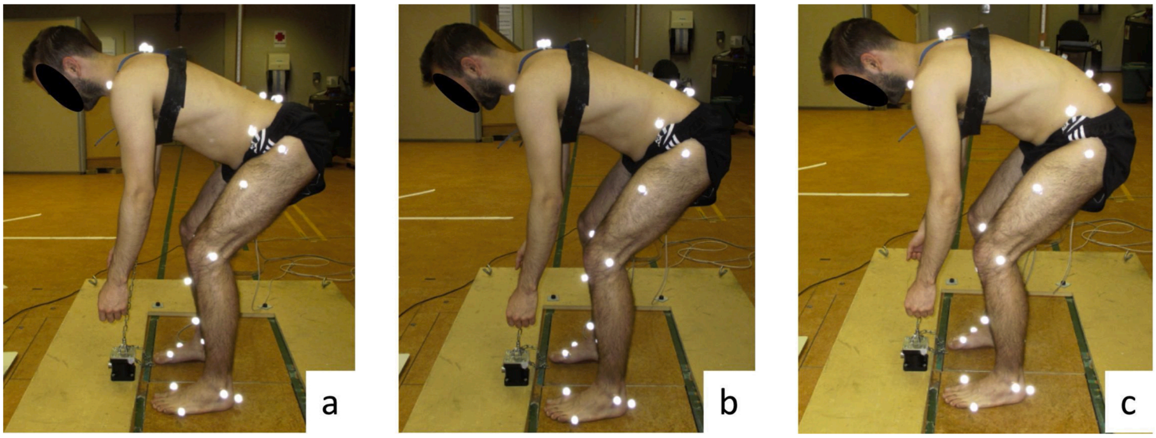

Fig. 1. The three lumbar postures adopted by participants: a) extended; b) mid-range; and c) flexed.

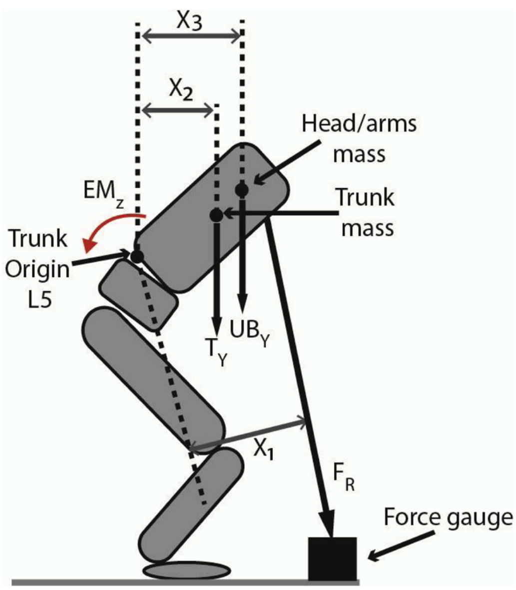

Fig. 2. Schematic diagram showing method used to calculate the extensor moment.

[20].

EMG signals were amplified (x500) using a Bortec Biomedical amplifier (Bortec Biomedical ltd, Alberta, Canada) with a 1–3 continuous variable gain, a 10GOhm input impedance, and a common mode rejection ratio of 115 dB. Sampled at 1200 Hz, the raw EMG data were demeaned and bandpass filtered between 10 and 500 Hz using a Butterworth 4th order recursive filter.

Two standardised approaches were used to obtain maximal voluntary isometric contraction (MVIC) for the normalisation of EMG of the two major muscle groups: 1) Biering-Sorensen technique [21] to obtain MVIC of the back extensors; and 2) the procedure described by Cholewicki and McGill [22] for the IO. The highest root mean square (RMS) value from three MVIC's from each muscle group was used to normalise measures of muscle activity during the test conditions.

EMG data that resulted in the maximum back extension force in each condition was used in subsequent analysis. A two second epoch of the EMG signal (1 s either side of the peak) was taken from this trial. All EMG signals were root mean squared (RMS) and normalised to their respective MVIC's, as follows:

Where:

$$\%EMG_N = \frac{\text{Task RMS} - \text{Resting RMS}}{\text{MVIC RMS} - \text{Resting RMS}} \times 100$$

Task RMS = RMS during the lifting task.

Resting RMS = RMS during relaxed prone lying.

MVIC RMS = RMS during the MVIC.

The maximal extensor moment was also measured in the Biering-Sorensen position for normalisation of moment for each lifting posture and subsequent caulation of NME. NME of the back extensors was determined based on a ratio of the normalised extensor moment (% EM_{ZN}) to normalised EMG (%EM_{ZN}/%EMG_N) for each trunk extensor muscle [9].

2.8. Data analysis

All data were initially checked for normality. A three-factor analysis of variance (ANOVA) with repeated measures was used to investigate the main effects of gender, lumbar posture (flexed, mid-range and extended) and muscle (UES, LES, multifidus, and IO) for each dependent measure. Dependent measures included maximum back extensor (EMz), hip and knee moments, muscle activation and NME. Where a significant main effect of lumbar posture was found, post hoc Bonferroni tests were performed to determine differences between the three lumbar postures and muscles. All statistical analysis was performed using IBM SPSS version 24.0 (SPSS Inc. Chicago) software package, with an alpha level of 0.05.

3. Results

3.1. Lumbar curvature

In the lifting position with the lumbar spine maximally flexed, participants adopted a mean peak flexion of 56.2° (95 % confidence intervals (CI) = 51.4° - 61.1°). This was similar to that measured when fully flexing the lumbar spine from an upright standing position (57.2°; 95 % CI = 52.7° - 62.8°). In the extended posture, participants maintained some lumbar flexion (mean angle = 22.7°; 95 %CI = 18.3° – 27.2°).

3.2. Back extensor moment

A main effect of gender was found, with males exerting significantly higher peak moments than females across all postures (Table 2).

When the extensor moment was normalised to moment produced in the Biering-Sorenson position, there was no main effect of gender, i.e. no significant difference in back extensor moment (%EM_{ZN}) between males and females. However, there was a significant main effect for posture

Table 2
Male and female mean (95 % Confidence Limits (CI)) trunk extensor moment (EM_Z), and combined male and female hip and knee extensor moment (kg/Nm) for each lumbar posture (extended, mid-range, flexed).

Lumbar posture	Trunk extensor moment – EM_Z (Nm)		Hip extensor moment (Kg/Nm)	Knee extensor moment (Kg/Nm)
	Males Mean (95 % CI)	Females Mean (95 % CI)	Mean (95 % CI)	Mean (95 % CI)
Extended	211.5 (196.5−226.6)	139.9 (124.9−155.0)	1.45 (1.29−1.60)	0.33 (0.22−0.44)
Mid-range	217.2 (201.8−232.7)	151.2 (135.6−166.5)	1.49 (1.32−1.65)	0.44 (0.33−0.56)
Flexed	227.3 (207.4−247.2)	175.2 (155.3−195.1)	1.49 (1.28−1.7)	0.33 (0.2−0.47)
Mean	218.7 (203.4−234.0)	155.4 (140.1−170.7)		

($P < 0.0001$), with post-hoc analysis showing a significant difference in $\%EM_{ZN}$ between the flexed and mid-range lumbar posture ($P = 0.003$), the mid-range and extended posture ($P = 0.016$), and the flexed and extended posture ($P = 0.0001$) (Fig. 3).

3.3. Hip and knee moment

Males exhibited significantly higher hip and knee moments than females ($P = 0.001$). However, when normalised to body weight, there was no difference between sexes. Lumbar posture had no effect on hip or knee moments ($P > 0.05$) (Table 2).

3.4. Muscle activity

There was no significant effect of gender on $\%EMG_N$, so male and female EMG data were pooled during subsequent analysis. All extensor muscles (UES, LES and multifidus) showed similar responses to changes in lumbar posture, with a mean decrease in $\%EMG_N$ of 10.9 % (95 % CI = 3.9 %–17.9 %; $P = 0.001$) from the extended to mid-range lumbar posture, and a 26.8 % (95 % CI = 17.1 %–36.4 %; $P = 0.001$) decrease when changing from the mid-range to flexed posture (Fig. 4). IO muscle activity was significantly lower (approximately 6–12 % MVIC) than paraspinal muscle activity and was not significantly different between postures.

Lumbar posture had a significant effect on NME ($P > 0.0001$), with mean NME increasing by approximately 25 % when moving from the extended (mean = 1.26 (95 % CI = 1.14–1.38) to mid-range (mean = 1.65; 95% CI = 1.41–1.9) lumbar posture ($P = 0.012$). An approximately three-fold increase was found when changing from mid-range to full flexion (mean = 3.73; 95 % CI = 2.81–4.65; $P = 0.007$).

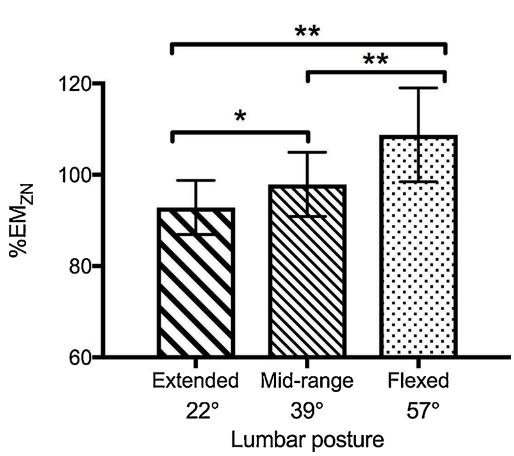

Fig. 3. Mean (95 % CI) normalised extensor moment ($\%EM_{ZN}$) for each lumbar posture (*$P < 0.05$; **$P < 0.005$). Lumbar flexion angle relative to upright standing (0°). Data pooled from male and female participants.

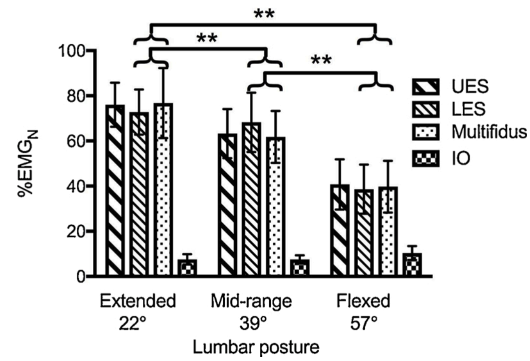

Fig. 4. Mean (95 % CI) normalised EMG muscle activity ($\%EMG_N$) for the three extensor muscle groups and IO at each lumbar posture (**$P < 0.005$). Lumbar flexion angle relative to upright standing (0°). Data pooled from male and female participants.

4. Discussion

This is the most comprehensive study to date exploring the influence of lumbar posture on trunk muscle recruitment, strength and efficiency during high intensity lifting. The study found that flexed lumbar spine lifting postures increased the body's ability to generate a trunk extensor moment and significantly improved NME. Conversely the lordotic / straight lumbar spine posture resulted in the lowest extensor moment and poorest NME.

These findings are in contrast to previous studies which have shown initial increases in the extensor moment when moving from an extended to mid-range lumbar posture, with no further increase thereafter [23–25]. These differences in findings may reflect the different methodologies adopted, such as the type of testing device used, the adopted test position, and the range of lumbar motion evaluated [8,9,24,25]. It is important to note that the extended lumbar postures reported in some studies that used fixation devices (including upright standing) [9,23] could not be replicated in the lifting position of the current study. This raises the question about the utility of previous findings when applying them to a manual lifting task and highlights that an extended lumbar posture associated with standing or lying may be unachievable when initiating a lift [26]. This finding is in line with power lifters who have been shown to lift in moderte to high degrees of lumbar flexion [27].

The increase in back extensor moment when changing from an extended to a fully flexed lumbar spine was associated with a corresponding decrease (approximately 40 %) in erector spinae and multifidus activity, and an increase in NME. This differed to the findings of Roy et al. [9] and Nordin et al. [8] who reported a plateauing of trunk muscle activity as the lumbar spine moved from upright standing to flexion. A notable difference between these studies and the current findings is that Roy et al. [9] and Nordin et al. [8] used sub-maximal ranges of lumbar flexion, whereas participants in the current study adopted maximum lumbar flexion.

The decreased NME in the extended posture was associated with higher levels of back extensor muscle activity (75 % of MVIC in the extended posture compared to 40 % of MVIC at full flexion). The reduction in the back extensor moment and NME in the extended posture may be due to the decreased force capabilities of the erector spinae and multifidus muscles as the spine extends. Biomechanical studies [28–30] suggest that when the lumbar spine is extended these muscles have relatively short sarcomere length, decreasing their ability to exert force. As a result of the inefficient length-tension relationship increased muscle activation is required and likely to increase metabolic demands and compressive forces on the lumbar spine [31,32]. In mid to end range lumbar flexion, these muscles approach an optimal length–tension relationship and the muscle's ability to generate force at lower activation levels increases [29,30].

The large increase in NME in the fully flexed posture may be due to the combined effects of improved force generating capacity of the erector spinae and the contribution from passive tissue of the spine (e.g. the posterior ligamentous system) as it approaches end range of flexion [33]. Moving beyond 80 % of lumbar flexion, which is equivalent to the change from mid-range to full flexion in our study, has been found to lead to an exponential increase in passive tissue contribution to the to the total extensor moment [32,33]. While a high NME ratio in full lumbar flexion may be beneficial for generating large extensor torques and reducing energy expenditure of the back extensors, the increased recruitment of posterior passive structures increases the likelihood of high anterior shear forces, and if repeated, creep on the lower lumbar spine [32,34].

Contrary to expectations, the relative activity of each division of the paravertebral muscles was similar in response to changes in lumbar posture. This is in contrast to studies that have shown reduced activation of LES and multifidus and increased activation of UES in end range lumbar flexion during low-load lifting [35,36]. These differences may be due to the level of loading on the lumbar spine. During low-load lifting, elastic energy from the stretched passive posterior elements of the spine, combined with the activity of the UES, is sufficient to resist loads without the additional contribution of the LES or multifidus muscles [36,37]. However, in line with our findings, during forceful extension of the spine the different divisions of ES appear to respond in a similar manner (increase or decrease levels of activation) [38] and the EMG - force relationships of the UES and LES are comparable [39].

Unlike the trunk extensors, IO co-activation was low (7–10 % of MVC) and unaffected by changes in lumbar posture, which is similar to the findings from studies involving heavy symmetrical lifting [34,40]. Abdominal muscle recruitment is a strategy commonly used by clinicians when treating and preventing low back pain, as this approach increases intra-abdominal pressure and improves spinal stiffness (stability) [41]. Studies have shown that in upright trunk postures where trunk extensor moments are low, the recruitment of abdominal muscles may serve to increase lumbar spine stability [22,42]. However, during the initiation of lifting, where the spine is relatively stable [22], increased abdominal muscle recruitment appears to be of limited benefit [43] and may lead to increased compression forces on the lumbar spine [44,45].

Hip and knee moments were unaffected by changes in lumbar posture. This is likely to have been due to the controlled knee angles adopted in this study. Hwang et al. [46] found increased hip and reduced knee moments in a stooped (flexed spine) compared to a squat lift (extended spine), and attributed it to less knee flexion in stooped lifting.

Together these findings may have implications for 'lifting advice' given to people engaged in manual work. Firstly, advice to maintain lumbar posture similar to upright standing during lifting appears to be unachievable. Secondly, instructions to maintain a lumbar lordosis (straighter back) resulted in significantly poorer neuro-muscular efficiency. Combined with the lack of *in vivo* evidence that lifting with a flexed back is associated with low back pain, the current lifting advise to 'lift with a straight or lordotic back' needs to be further questioned.

5. Conclusions

This study demonstrated that flexed lumbar spine lifting postures increased the body's ability to generate a trunk extensor moment and significantly improved NME. Conversely, the lordotic / straight lumbar spine postures resulted in the lowest extensor moment and poorest NME. These findings may have implications for the lifting advice given to manual workers who undertake heavy lifting tasks throughout the day.

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Declaration of Competing Interest

The authors report no declarations of interest.

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