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Comparison of glenohumeral and humerothoracical range of motion in healthy controls, osteoarthritic patients and patients after total shoulder arthroplasty performing different activities of daily living

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ABSTRACT

Purpose: The purpose of this study was to examine how total shoulder arthroplasty improves performance of activities of daily living compared to patients with glenohumeral osteoarthritis and how they perform compared to healthy controls.

Methods: Glenohumeral and humerothoracical elevation used by patients with primary osteoarthritis (12 participants, 16 shoulders), after total shoulder arthroplasty (16 participants, 24 shoulders) and healthy controls (11 participants, 22 shoulders) for four different activities of daily living were assessed using 3D motion analysis. Analysis of range of motion and angle time series was performed.

Results: Range of motion used for activities of daily living was better in patients treated with anatomical total shoulder arthroplasty than in patients with primary glenohumeral osteoarthritis. Although it was still reduced compared to healthy individuals. Angle time series showed improved kinematics in patients with total shoulder arthroplasty compared to patients with glenohumeral osteoarthritis. Both glenohumeral and humerothoracical elevation kinematic time series were in almost all cases in between the control group's and the osteoarthritis group's.

Conclusion: Total shoulder arthroplasty improves performance of activities of daily living in patients with primary glenohumeral osteoarthritis but cannot restore the full range of Motion compared to healthy controls. A prospective study with pre- and postoperative examinations is necessary to understand to understand how preoperative status influences the postoperative results.

1. Introduction

Glenohumeral osteoarthritis (OA) can either be primary (i.e. idiopathic) or secondary due to preexisting shoulder pathology, e.g. posttraumatic, rheumatoid, and others. Treatment depends on stage of OA, and symptoms (pain, limitation of range of motion (ROM), inability to handle everyday life). Conservative treatment options include analgesic therapy, physiotherapy and intraarticular injections. When conservative treatment does not provide sufficient relief, implantation of a shoulder endoprosthesis can be considered [1,2]. Today mainly three types of implants are available: anatomically shaped hemi shoulder arthroplasty replaces only the humeral head, while anatomical total shoulder arthroplasty (TSA) replaces both the humeral head and the glenoid. Reversed total shoulder arthroplasty replaces the glenoid with a ball-shaped component and the humeral head with a socket-shaped component. TSA is reported to provide both pain relief and improvement of ROM [1,3–6]. ROM is mostly measured as elevation in frontal and sagittal plane and rotation using a goniometer. Even though ROM on average improves after TSA, it still remains reduced compared to healthy age-matched individuals [3]. However, in most everyday tasks full ROM is not necessary. To measure improvement for patients standardized Activities of Daily Living (ADL) have been used [3,7–10]. Many scores, e.g. Constant-Murley Score [11], DASH [12] and ASES [13], include ADLs. However, self-reported ability and objective judgement can differ greatly [14]. Furthermore, self-reporting scales only give a quick overview wether or not the patient is able to perform a task. In many cases basic ADLs can still be executed with OA, although they might be painful and more difficult to execute. 3D motion analysis is an objective tool to record and compare human motion. It can deliver more insight as to how joint kinematics are altered due to OA and how

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they improve after treatment with TSA. Few studies examining ADLs in patients with TSA are available. Most studies only evaluated humerothoracial motion by feature analysis, i.e. comparison of ROM used and peak angles [3,9,15]. To our knowledge only one study by Veeger et al. [16] that examined ADLs in patients with TSA reported kinematic time series for a hair-combing task. This is the first study that statistically compared both ROM values and kinematic time series for four different ADLs for both patients with OA and after TSA and healthy control subjects.

We hypothesized patients with OA would show less glenohumeral (GH) and humerothoracical (HT) elevation than asymptomatic controls. Furthermore, we hypothesized that patients treated with TSA would show more GH and HT elevation than OA patients, although still less than asymptomatic controls.

2. Materials and methods

A total of 37 individuals participated in this study. The study was approved by the institutional ethics committee (S-657/2015) and all participants signed written informed consent prior to participation.

2.1. OA group

12 patients (8 male, 4 female) with a mean age of 66.3 ± 7.5 years (values after " ± "reflect standard deviation (SD)) affected by glenohumeral OA were included. 8 were affected unilaterally and 12 were affected bilaterally, resulting in a total of 16 shoulders that were examined. Two "unilaterally affected" patients had already received anatomical TSA on the other side and were included in both OA and TSA group. All patients showed a stage 3 OA according to Samilson and Prieto [17] with a caudal osteophyte with a length greater than 7 mm in the latest available x-ray in anterior-posterior projection.

2.2. TSA group

16 patients with a mean age of 71.2 ± 5.2 years who received anatomical TSA were examined 5.4 ± 2.1 years after surgery. 8 patients were treated unilaterally and 8 patients were treated bilaterally, resulting in 24 shoulders that were examined. As mentioned before, two patients were treated with TSA on one side and had OA on the other side and were included in both groups. In 13 cases a stemmed prosthesis (Aequalis Shoulder, Tornier, Lyon, France) was implemented and in 11 cases a stemless prosthesis (T.E.S.S., Zimmer Biomet, Warsaw, USA) was implemented. Patients with prosthesis infection or revised prosthesis were excluded. In all cases primary glenohumeral OA was the indication for implementation.

2.3. Control group

11 persons with mean age of 69.6 ± 5.3 years with no history of shoulder trauma, surgery or chronic shoulder pain were examined bilaterally and included as a control group. See Table 1 for more demographic details about the groups.

Table 1
Demographic data for the three groups. * Two patients were included in both OA and TSA group.

	OA	TSA	Control	Total
N Subjects	12	16	11	37*
Age [a]	66.3 ± 7.5	71.2 ± 5.2	69.6 ± 5.3	69.1 ± 6.2
Sex [male/female]	8 / 4	7 / 9	4 / 7	18 / 19
Dominant Side [right/left]	12 / 0	15 / 1	9 / 2	34 / 3
N Shoulders	16	24	22	62
Side [right/left]	7 / 9	16 / 8	11 / 11	34 / 28
Time since surgery [a]	–	5.4 ± 2.1	–	–

2.4. Study protocol

At first all participants were clinically examined to exclude any unknown shoulder pathologies. After that all participants were examined using three-dimensional motion analysis using an optoelectronic system consisting out of 12 infrared-cameras (T40-S, Vicon Motion Systems, Oxford, United Kingdom). The GH center of rotation was calculated from dynamic elevation movements in frontal and sagittal plane using a least squares method [18] with a bias compensation algorithm [19]. A biomechanical model consisting out of 5 segments per side (thorax, clavicle, scapula, humerus and forearm) was used. Anatomical landmarks were either tracked directly via markers or digitized with a pointer device using static reference frames. Joint kinematics were calculated using Euler/Cardan Angles. Recommendations of the International Society of Biomechanics (ISB) for anatomical coordinate systems and rotation sequences were followed [20]. A marker cluster on the acromion was used for tracking of the scapula and another marker cluster was placed on the humerus.

Patients were seated on a stool and performed four ADLs: perineal care (PC), washing axilla (WA), combing hair (CH) and taking a book from a shelf (BS). The starting and finishing position for each movement cycle was sitting upright with 90° knee flexion and both hands placed on the upper legs. For AC participants were asked to move their hand to their lower perianal region, imitate an upward wiping movement and return to the starting position. For WA participants were handed a paper towel and asked to move their hands to the upper contralateral axilla, wipe downwards and return to the starting position. No specific instructions for the arm lifting of the contralateral side were given. For CH participants were handed a hairbrush, which for hygienic reasons was used upside down. They were asked to move the brush to the frontal hairline, brush backwards to the occiput keeping contact to the head and return to the starting position. For BS a tripod with a board on top was used. The height was adjusted to match the participants eyebrows and the distance was adjusted so that the participant could grab the book with their elbow fully extended. They were asked to grab the book move it to the side of their body and put it back on the board and return to the starting position.

2.5. Data processing

Elevation of the humerus relative to the thorax (HT) and relative to the scapula (GH) was calculated for all ADLs using Matlab 2017b (The MathWorks, Natick, USA). Between 1 and 5 correctly executed repetitions were available per shoulder and ADL. The average used ROM for GH and HT elevation for each shoulder and ADL was calculated. ROM was calculated as the mean difference between maximum and minimum elevation. Furthermore, time normalized mean kinematic curves were calculated.

2.6. Statistics

All statistical analysis on extracted data (i.e. ROM and peak angles) was done using SPSS 24 (IBM, Armonk, USA). At first, data was evaluated graphically for normal distribution using Q-Q plots. Normally distributed data was tested for homogenity of the variances using Levene's test. One-way ANOVA was used for homogenic and Welch-ANOVA for non-homogenic data. Tukey-Kramer post-hoc tests were used for significant results. P-values below 0.05 were considered significant.

Kinematic time series were evaluated using statistical parametric mapping (SPM). SPM was originally developed for use in neurologic research for evaluation of radiologic images [21]. Recently it has been adapted to examine one-dimensional data, e.g. kinematic time series [22]. Basically, the relevant test-statistic (e.g. *t*-test or ANOVA) is

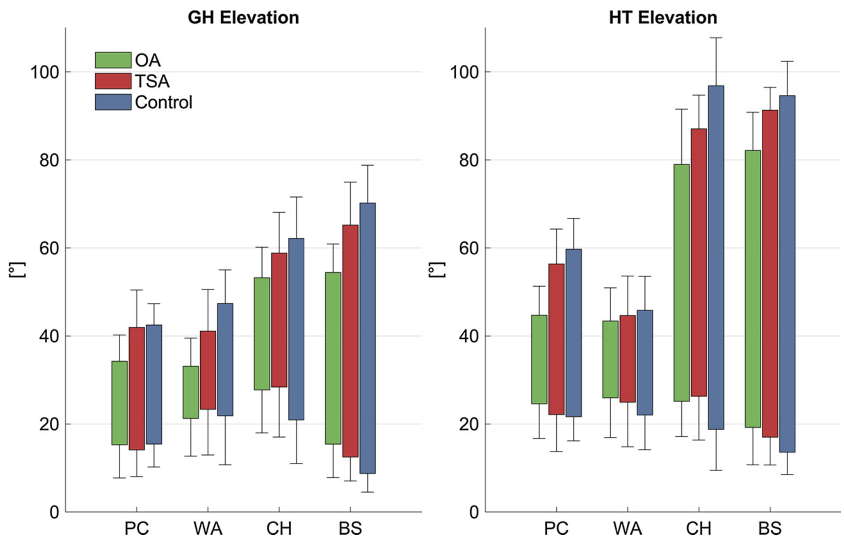

Fig. 1. ROM used during ADL. Control Group in blue, TSA Group in red, OA Group in green. Whiskers represent SD of minimum and maximum values (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

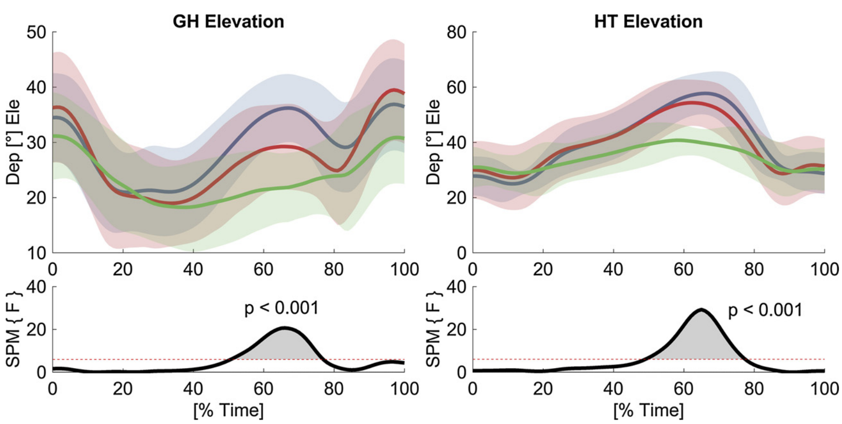

Fig. 2. Kinematic time series for PC. Control Group in blue, TSA Group in red, OA Group in green. Bands represent +/- SD. Lower Plots show SPM ANOVA with grey clusters indicating significant differences between the groups (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

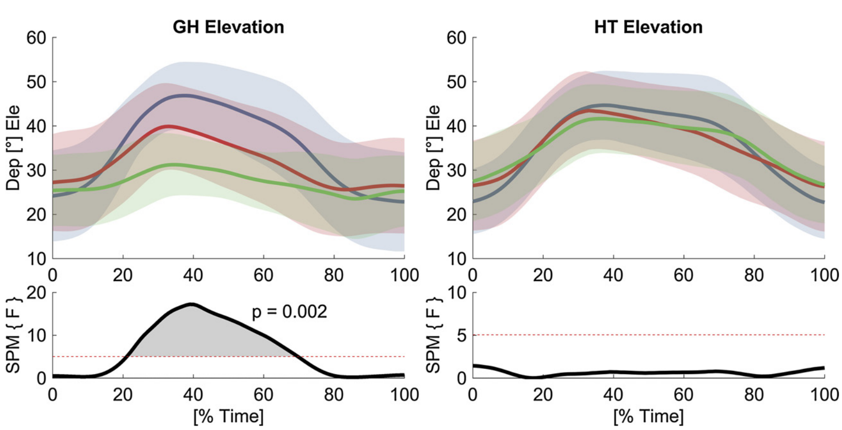

Fig. 3. Kinematic time series for WA. Control Group in blue, TSA Group in red, OA Group in green. Bands represent +/- SD. Lower Plots show SPM ANOVA with grey clusters indicating significant differences between the groups (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

calculated for each data point. Random Field Theory is used to determine a threshold value based on the smoothness of the curve. When values higher than the threshold occur, a single p-value for the whole cluster is calculated instead of one for every data point. This approach allows more insight compared to the massive data-reduction, which occurs in 0-dimensional feature analysis. On the other hand, it omits multiple testing problems that would occur when calculating p-values for every data point on a curve. The Matlab version of the SPM1D software package by T. Pataky (v 0.4; www.spm1d.org) was used for evaluation [23]. A oneway-ANOVA was used for each time series.

3. Results

One participant in the OA group could not fully execute the WA and BS task. The participant was asked to execute the task as far as possible and the resulting ROM and curve was then included in the analysis. All other participants were able to execute all four ADLs.

3.1. ROM feature analysis

GH ROM used for PC was 20.6° ± 6.6° in OA, 29.9° ± 8.9° in TSA

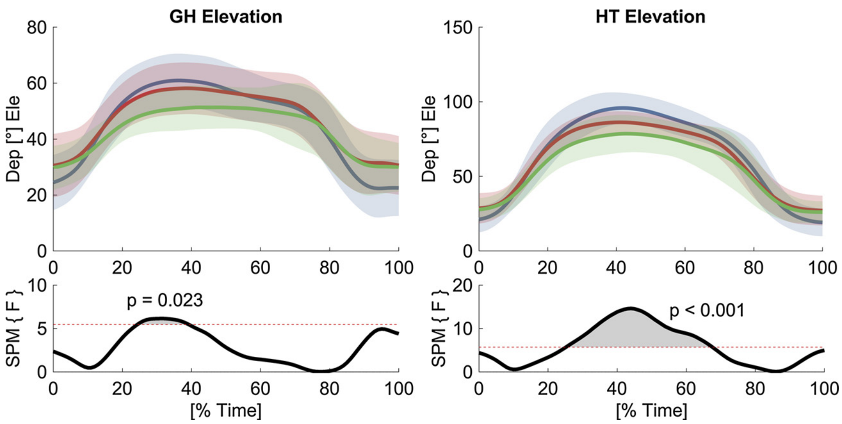

Fig. 4. Kinematic time series for CH. Control Group in blue, TSA Group in red, OA Group in green. Bands represent +/- SD. Lower Plots show SPM ANOVA with grey clusters indicating significant differences between the groups (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

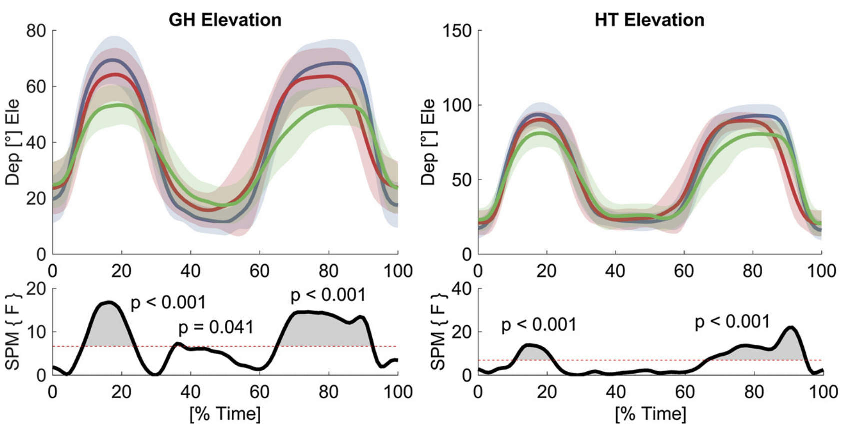

Fig. 5. Kinematic time series for BS. Control Group in blue, TSA Group in red, OA Group in green. Bands represent +/- SD. Lower Plots show SPM ANOVA with grey clusters indicating significant differences between the groups (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

and 29.2° ± 4.6° in Control ($p < 0.001$). Post-hoc tests showed that there was a significant difference between OA and Control ($p = 0.001$) and between OA and TSA ($p < 0.001$).

HT ROM used for PC was 22.0° ± 7.4° in OA, 35.8° ± 10.3° in TSA and 40.1° ± 8.1° in Control ($p < 0.001$). Post-hoc tests showed that there was a significant difference between OA and Control ($p < 0.001$) and between OA and TSA ($p < 0.001$).

GH ROM used for WA was 12.6° ± 4.8° in OA, 18.8° ± 7.3° in TSA and 26.5° ± 8.3° in Control ($p < 0.001$). Post-hoc tests showed that there was a significant difference between OA and Control ($p < 0.001$), OA and TSA ($p = 0.024$) and between TSA and Control ($p = 0.002$).

HT ROM used for WA was 18.2° ± 5.4° in OA, 20.7° ± 5.5° in TSA and 24.6° ± 5.1° in Control ($p = 0.002$). Post-hoc tests showed that there was a significant difference between OA and Control ($p = 0.002$) and between TSA and Control ($p = 0.046$).

GH ROM used for CH was 26.6° ± 11.4° in OA, 31.6° ± 10.1° in TSA and 42.1° ± 12.5° in Control ($p < 0.001$). Post-hoc tests showed that there was a significant difference between OA and Control ($p < 0.001$) and between TSA and Control ($p = 0.007$).

HT ROM used for CH was 55.2° ± 12.6° in OA, 62.2° ± 10.4° in TSA and 78.9° ± 15.4° in Control ($p < 0.001$). Post-hoc tests showed that there was a significant difference between OA and Control ($p < 0.001$) and between OA and TSA ($p < 0.001$).

GH ROM used for BS was 40.4° ± 11.6° in OA, 54.2° ± 11.2° in TSA and 63.3° ± 10.4° in Control ($p < 0.001$). Post-hoc tests showed that there was a significant difference between OA and Control ($p < 0.001$), between OA and TSA ($p = 0.001$) and between TSA and Control ($p = 0.019$).

HT ROM used for BS was 64.6° ± 12.1° in OA, 75.7° ± 7.7° in TSA and 82.6° ± 9.2° in Control ($p < 0.001$). Post-hoc tests showed that there was a significant difference between OA and Control ($p < 0.001$), between OA and TSA ($p = 0.002$) and between TSA and Control ($p = 0.044$).

Fig. 1 shows mean minimum and maximum angle values.

3.2. SPM curve analysis

For PC both GH and HT elevation curves were lowest in the OA Group and highest in the Control group with the TSA group in-between. HT elevation showed an almost similar curve for the Control group and TSA group with the OA group's curve being lower. SPM ANOVA showed a significant difference between the elevation curves for the three groups in both GH elevation ($p < 0.001$) and HT elevation ($p < 0.001$) (Fig. 2).

For WA the GH elevation curve of the OA group was the lowest, the Control group's curve the highest with TSA in-between. SPM ANOVA showed a significant difference for GH elevation during the performance of the ADL ($p = 0.002$). In contrast HT elevations curves were rather similar and did not show any significant differences (Fig. 3).

For CH the GH elevation curve of OA was below TSA and Control, which were relatively close during the activity. HT elevation was lowest in OA and highest in Control with TSA in-between. SPM ANOVA showed only a short significantly different interval in GH elevation ($p = 0.023$), but a large cluster for HT elevation ($p < 0.001$) (Fig. 4).

For BS both the GH elevation curve and HT elevation curve were lowest in the OA group and highest in the Control group with the TSA group's curve in-between. SPM ANOVA showed a significant difference between the groups for both GH and HT elevation at both peaks (grabbing the book from the shelf and putting it back on it) ($p < 0.001$) and a small significant cluster in the GH elevation curve when the book was held beside the body ($p = 0.041$) (Fig. 5).

4. Discussion

The purpose of this study was to compare the performance of ADLs of patients after TSA with both healthy controls and patients with primary glenohumeral OA that have not been surgically treated in order to assess to what extent patients can expect normalization.

Overall the ROM used and the averaged elevation over time was highest in the Control group and lowest in the OA group. There were significant differences for ROM between OA and Control for both GH and HT elevation in all four ADLs. TSA group's ROM values were always between both of the two other groups', except for GH elevation in PC, which was slightly higher than the Control group's. Looking at the GH elevation curve the source of this phenomenon becomes obvious: The peak GH elevation is at the rest position and the lowest elevation at the start of the activity (reaching the lower perineal region). The GH elevation curve during the activity itself lays between those two extremes, hence it does not contribute to the ROM value. This shows one of the disadvantages of 0-dimensional feature analysis. Analysis of the time normalized curves can give a better picture and identify at what point differences occur.

The time normalized curves showed a similar pattern for both PC and BS. For WA the curves for HT elevation did not differ significantly, although the GH elevation curves did. This could indicate that the shoulder girdle was used to compensate for limited GH elevation capability by the OA and the TSA group, while participants in the Control group mostly used a higher amount of glenohumeral elevation. Previous studies showed a reduced scapulohumeral rhythm for patients with OA [24,25] and after TSA [24,26–28]. For CH only a small difference could be shown for GH elevation, although visually there is a difference between OA and the other two. A higher amount of variance between subjects in performing this particular ADL could explain, why the difference was not significant. HT elevation however, showed the same pattern as PC and BS.

To our knowledge, there is only one other study that quantitatively compared performance of ADLs in patients with OA, TSA and healthy controls (in this case pre- and postoperative) [9]. Comparison to data of this study is difficult although the same set of ADLs was used, since projection angles were used instead of euler-angles. Movements to perform ADLs are not constraint to certain anatomical planes. Movements outside these planes project also on other planes, e.g. 90° elevation in the scapular plane results in 90° forward flexion and abduction even though the patient might not be able to reach 90° of abduction when asked to perform abduction strictly in the frontal plane. Therefore values of projection angles can be higher than the pure elevation calculated as an euler-angle. The comparison is even more complicated since only ROM values are stated. There is a large effect on projection angles, when the zero degree line is crossed. E.g. moving the 90° abducted arm forwards and backwards would result in a 180° ROM value for flexion/extension. A third point is that the study did not include glenohumeral kinematics. We can therefore only compare the humerothoracical elevation, which reflects in the flexion/extension and abduction/adduction projection angles. Overall their study also found an improvement in the TSA group's ROM for most ADLs compared to the preoperative status, similar to our findings. The difference between the control group and the TSA group at three years postoperatively appears to be smaller than in our study, although this can be due to the abovementioned methodic differences.

Limitations of this study were the small group size and violation of the presumption of independence of observations as two participants were included in two groups. Furthermore, a prospective design with pre- and postoperative results would be favorable since it is unclear if the OA group's abilities matches the TSA group's preoperative status. It would be also helpful to gain an understanding of how preoperative status influences postoperative ability to perform ADLs in order to help to improve indication for surgical treatment.

5. Conclusion

Total shoulder arthroplasty improves performance of ADLs in patients with primary glenohumeral OA but cannot restore the full ROM in performing ADLs compared to healthy controls.

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