Flat vs. concave tibial joint surface in total knee arthroplasty

Randomized evaluation of 39 cases using radiostereometry

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ABSTRACT – 40 patients with non-inflammatory arthrosis and minor preoperative deformity (⁄ 5°) were operated on with an AMK type (DePuy, Johnson & Johnson) total knee arthroplasty (TKA). The posterior cruciate ligament was retained. The patients were divided into those with a flat (terminology of the manufacturer: standard) or a concave (terminology of the manufacturer: constrained) polyethylene insert (20 in each group). Radiostereometric (RSA) examinations were done postoperatively and after 3, 12 and 24 months. The median absolute rotations of the tibial inserts varied between 0.12 and 0.24 (range 0.00–1.54) degrees, with no differences between the 2 groups. The median maximum total-point motions (flat/concave = 0.41/0.42 mm), the maximum subsidence or lift-off did not differ. The Hospital for Special Surgery knee score and the patients' opinion about the operation, based on their preoperative expectations, showed little, if any, differences. At 2 years, 10 of 20 patients with flat and 13 of 19 with concave inserts regarded their knee function as normal or almost so.

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Radiostereometric (RSA) studies of tibial component fixation in total knee arthroplasty have mainly focused on the use or non-use of cement (Ryd et al. 1990, Nilsson et al. 1991, 1999, Nilsson and Kärrholm 1992, 1993, Ryd and Toksvig-Larsen 1993, Ryd and Egund 1995, Toksvig-Larsen et al. 1998, Önsten et al. 1998). In those studies, various designs of the joint area were used, but not specifically investigated. 15 years ago, there was a tendency to use flatter tibial components (Hungerford and Krackow 1985, Landon et al. 1986, Thatcher et al. 1987), because some more constrained designs proved to be incompatible with retention of the posterior cruciate ligament. This was considered beneficial because retention of the ligament was thought to improve function. A constrained design could also be expected to transmit stronger forces to the cement/bone or implant/bone interface(s), which would increase the risk of clinical loosening. On the other hand, flat tibial surfaces have raised concerns about high contact stresses (Bartel et al. 1986) resulting in wear and delamination of the polyethylene (Engh et al. 1992, Bosco et al. 1994, Toksvig-Larsen et al. 1996, Kadoya et al. 1998, Wimmer et al. 1998). Both flat and concave tibial inserts are available, but to our knowledge, this has not been studied in a randomized comparison.

We used radiostereometry to measure migration of tibial components in total knee arthroplasty with flat or concave joint area up to 2 years postoperatively. Our hypothesis was that use of a shallower joint area would result in smaller micromovements. The patient's expectations about the operation and their opinion of the results were recorded to evaluate whether the choice of joint area had any effect on the clinical outcome.

Patients and methods

40 consecutive patients (median age 69 (51–83) years, 31 females) with arthrosis (Ahlbäck (1968) grades 2–4) and a varus/valgus deformity of 5° or less were included during years 1995–1997. The

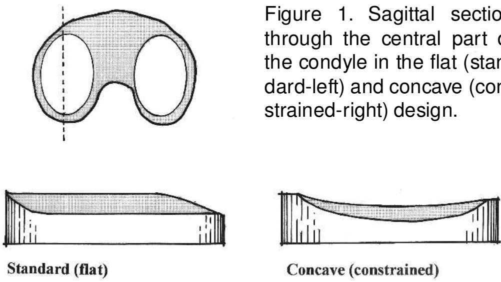

Figure 1. Sagittal section through the central part of the condyle in the flat (standard-left) and concave (constrained-right) design.

measurements made by the radiologist on long radiographs of the whole leg were used to determine the degree of varus/valgus deformity. They were all operated on with an AMK (DePuy, Johnson & Johnson) total knee arthroplasty. 20 patients received a comparatively flat (F, manufacturer terminology: standard) and 20 a more concave (C, manufacturer terminology: constrained) tibial insert (Figure 1). Mechanical tests shows that the constrained (Figure 1) design provides about 6 times greater resistance to anterior (375 lbs axial load) and 30% more resistance to posterior displacements (650 lbs axial load) at 0º extension. At 430 lbs axial compression, the rotational stability is about 6 times greater for the concave than with the flat insert (Postak et al. 1992).

The patients were stratified, using a minimization method (Pocock 1983). The stratification was based

Table 1. Patient data and clinical results. Median, *range* (when applicable)

	Type of tibial insert	
	Flat	Concave [a]
Number of patients	20	20 (19)
Age (years)	70 *51–77*	68 *59–83*
Gender (M/F)	2 / 18	7 / 13
Type of arthrosis (M/L)	14 / 6	16 / 4
HSS score		
Preop	66 *51–80*	60 *43–76*
1 year	79 *52–95*	81 *54–94*
2 years	82 *48–97*	86 *66–97*
Difference 0–1 year	15 *-11–35*	22 *-1–43*
Difference 0–2 years	16 *-15–39*	27 *1–49*
Feeling of instability		
1 year (N/Y)	17 / 3	15 / 5
2 years (N/Y)	15 / 5	16 / 3
Does your knee feel normal?		
1 year (Y/A/N) [b]	0 / 14 / 6	0 / 13 / 7
2 years (Y/A/N) [b]	2 / 8 / 10	4 / 9 / 6

[a] One patient died between the 1- and 2-year follow-ups
[b] Yes/Almost/No

operatively and 3, 12 and 24 months after the operation. The following data were chosen to represent migration of the tibial component: the absolute value of rotations around the transverse, longitudinal and sagittal axes, maximum subsidence, maximum lift-off and maximum total point motion (MTPM, Nilsson and Kärrholm 1992, Nilsson and Kärrholm 1993, Regnér et al. 1998, Nilsson et al. 1999). Radiostereometric studies could be accurately evaluated in 37 patients (20 flat, 17 concave). In 1 patient (concave insert), sufficient prosthetic markers were not visualized postoperatively (but at the following examination). These results are presented separately. 1 patient was given too few tantalum markers during the operation. 1 patient (female, concave insert) died from causes not related to the TKA between the 1- and 2-year follow-up.

The PT-angle (position of the tibial component) on the anteroposterior (AP) view and the PTS-angle (position of the tibial component sagittal) were measured by the method of Albrektsson and Herberts (1988). The position of the femoral component was recorded by measuring the femoral angle (FAP) on the anteroposterior view (Ewald 1989).

The HKA-angles (Hagstedt et al. 1980, Tjörnstrand et al. 1981) were re-measured by two

Table 2. Absolute rotations (transverse, longitudinal and sagittal axes), maximum subsidence, maximum lift-off and maximum total point motion of the flat (F) and concave (C) polyethylene tibial trays

	Median		95% confidence limits of mean [a]		Minimum		Maximum	
	F	C	F	C	F	C	F	C
Absolute rotations (degrees)								
Anterior/posterior tilt	0.15	0.14	0.09–0.39	0.09–0.37	0.02	0.02	1.42	1.18
Internal/external rotation	0.24	0.22	0.18–0.53	0.16–0.44	0.00	0.00	1.54	0.94
Varus/valgus tilt	0.16	0.12	0.13–0.31	0.09–0.23	0.02	0.03	0.87	0.55
Maximum total point motion (mm)	0.41	0.42	0.33–0.91	0.34–0.58	0.20	0.11	2.92	1.04
Maximum subsidence (mm)	-0.07	-0.13	-0.20– -0.04	-0.26– -0.03	-0.62	-0.86	0.11	0.16
Maximum lift-off (mm)	0.29	0.20	0.17–0.55	0.10–0.24	0.03	0.04	1.31	0.45

[a] mean value ± (2.086 x SE of mean)

of the authors on the preoperative radiographs and radiographs from the follow-up at 2 years. Radiolucent lines (RLL) under the tibial tray and around the stem were measured by the Knee Society X-ray score (Ewald 1989). With a 7-region tibial component, such as the AMK design, nonprogressive RLL's of 0–4 mm are considered probably insignificant, 5–9 mm should be closely followed for progression and 10 mm or more signifies possible or impending failure (regardless of symptoms).

Clinical evaluation

The patients were examined preoperatively, using the Hospital for Special Surgery knee score (HSS, Ranawat and Shine 1973). Preoperatively, they were asked to fill in questionnaires about their expectations about the results of the operation. At the 1- and 2-year follow-ups, the patients were asked whether or not their expectations had been fulfilled. They also filled in a questionnaire about the stability and overall function of their knee. Stability was divided into 3 grades (always stable regardless of type of activity/occasional instability when climbing stairs or on uneven ground/continual instability when walking). Their function was divided into 3 classes (my knee feels normal/almost normal/definitely abnormal). The patients received the questionnaire by mail 2 weeks before the visit to the outpatient clinic. The reproducibility of this questionnaire was evaluated in 18 patients who were asked to fill in the form a second time 2 weeks after the 1- or 2-year follow-up.

One patient (female, flat insert) developed postoperative septicemia due to intestinal gangrene. She was operated on with partial resection of the colon and received intensive care for 1–2 weeks. At this time, she also developed partial necrosis of the wound. At the 1-year follow-up the skin had healed on conservative treatment with no signs of deep infection. At 2 years, she felt pain walking downstairs, probably due to a reduced range of motion (0–45°).

Statistics

The Mann-Whitney U-test was used to compare the RSA parameters at 2 years. This test and Fisher's test were used to compare the clinical outcome, including the HSS score. Spearman's nonparametric correlation was used to evaluate possible associations between the position of the components or the extension of radiolucent lines at 2 years and migration. Median values and ranges are presented in the text. On the basis of the scatter of data seen, the study design, with 80% probability, could detect a difference ($p < 0.05$) in maximum subsidence, MTPM and rotations of 0.2 mm, 0.4 mm and about 0.3–0.4 degrees, respectively. The reproducibility of the questionaire was evaluated by calculation of Kendall's tau.

The study was approved by the local Ethics Committee.

Results

Rotations of the tibial component. After 2 years, the median absolute rotations of the flat inserts varied between 0.15 and 0.24 (range 0.00–1.54) degrees and those of concave inserts between 0.12 and 0.22 (0.00–1.18) degrees which was not sig-

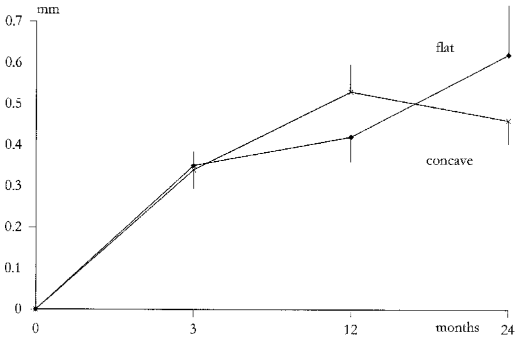

Figure 2. Maximum total point motion (mean, SE of mean) at 3 months, 1 and 2 years after the operation.

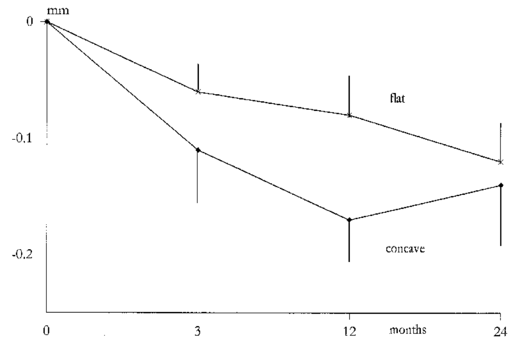

Figure 3. Maxiumum subsidence (mean, SE of mean) at 3 months, 1 and 2 years after the operation.

nificant (F vs. C: p = 0.4–0.9; Table 2).

Translations of the tibial component. The median maximum total point motion (MTPM) was about the same in the 2 groups (F: 0.41 (0.2–2.9) mm, C: 0.42 (0.1–1.0) mm; F vs. C: p = 0.8, Table 2, Figure 2). The maximum subsidence of any of the peripheral points of measurement were -0.07 (-0.62–0.11) mm vs. -0.13 (-0.86–0.16) mm in the flat and concave groups, respectively (F vs. C: p = 0.7, Table 2, Figure 3). The maximum lift-off of the edge of the tibial component amounted to 0.29 (0.03–1.31) mm in the flat and 0.20 (0.04–0.45) mm in the concave group (F vs. C: p = 0.2).

Cases with incomplete observations. The tibial component in the patient who died (C) after 1 year had rotated 0.09–0.32° around the three cardinal axes. Its translations were 0.47/-0.08/0.34 mm (MTPM, max. subsidence, max. lift-off). In the patient who could be studied only 3–24 months (C), the corresponding values were 0.08–0.32° and 0.31/-0.13 /0.04 mm.

Conventional radiography

The pre- and postoperative HKA-angles and the positioning of the tibial and femoral components (FAP-, PTS- and PT-angles) did not differ between the 2 groups (p = 0.1–0.8, Table 3). There was a tendency to increased rotations around the longitudinal axis with an increasing posterior slope of the tibial component (F: r = -0.54, p = 0.01; C: r = -0.56, p = 0.02). In the concave group, we saw a tendency to increased rotation about the transverse axis with increasing varus position of the component (r =-0.54, p = 0.02).

At 2 years, the median (added) widths of the radiolucent lines according to the Knee Society system, were 2 (0–4) mm and 1 mm (0–4) mm in F and C, respectively (F vs. C: p = 0.5). The radiolucencies were most frequently located medially below the tibial tray (i.e., zone 1). There was no correlation between the radiolucent lines and any of the migration parameters (r = -0.32–0.31, p = 0.2–0.9).

Table 3. Inclination of the prosthetic components and HKA angle (median, *range*)

	Flat		Concave	
Femoral component				
FAP-angle[1]	95	*93–96*	94	*92–96*
Tibial joint component				
PT-angle[1]	89	*87–90*	89	*87–91*
PTS-angle[2]	87	*83–89*	87	*83–90*
HKA-angle preop.[3,4]	177	*173–182*	176	*175–185*
HKA-angle 2 years[3]	178	*175–184*	178	*174–181*

[1] <90 = varus tilt
[2] <90 = posterior tilt
[3] <180 = varus
[4] results from the second evaluation, see text

Clinical results

At 2 years, 9/12 (F/C) patients reported that the pain relief corresponded to their expectations. Further, 7/6 reported improvement, but not quite according to their expectations. 4 patients with flat and 1 with concave insert were disappointed, because they felt that the pain was unchanged or had become worse. The expectation that seemed to be most consistently fulfilled was improvement in walking ability in the group with concave inserts. 8 patients with

Table 4. Expectations of the operation and results at 2 years

	Preoperatively Type of polyethylene insert		2 years Type of polyethylene insert	
	Flat [a]	Concave [a]	Flat [b]	Concave [b]
Number of patients	20	19	20	19
Relief of pain	0 / 0 / 5 / 15	1 / 1 / 1 / 16	3 / 1 / 7 / 9	1 / 0 / 6 / 12
Walking	0 / 0 / 0 / 20	1 / 0 / 3 / 15	2 / 1 / 8 / 9	0 / 0 / 8 / 11
Stair-climbing	0 / 0 / 4 / 16	1 / 1 / 1 / 16	3 / 5 / 7 / 5	1 / 3 / 7 / 8
Social activities	1 / 5 / 4 / 10	5 / 0 / 5 / 9	2 / 6 / 4 / 8	1 / 4 / 3 / 11
Stability	0 / 1 / 1 / 18	2 / 0 / 1 / 16	3 / 4 / 6 / 7	1 / 1 / 4 / 13
Sleep	2 / 3 / 6 / 9	3 / 4 / 3 / 9	2 / 9 / 3 / 6	2 / 5 / 5 / 7
Straight leg	4 / 4 / 2 / 10	5 / 3 / 1 / 10	3 / 7 / 1 / 9	2 / 1 / 2 / 14

[a] not / slight / fairly / very important.
[b] worse / no change / better / as expected.

Table 5. Expectations of the operation and results at 2 years

	Preoperatively		2 years [a]		P-value
	Flat [b]	Con. [b]	Flat [c]	Con. [c]	
Relief of pain	0/20	2/17	4/16	1/16	0.3
Walking	0/20	1/18	3/17	0/18	0.2
Stair-climbing	0/20	2/17	8/12	3/14	0.2
Social activities	6/14	5/14	6/8	4/10	0.7
Stability	1/19	2/17	7/12	1/16	0.04
Sleep	5/15	7/12	8/7	5/7	0.7
Straight leg	8/12	8/11	5/7	2/9	0.4

[a] only includes answers from patients who preoperatively selected this item as important / very important.
[b] little, if any, importance/ fairly or very important.
[c] worse or no change / better or as expected.

Table 6. Review of the questionnaire in 18 patients. Fulfillment of expectations in 4 grades

	Difference occasions 1–2 [a]	τ [b]	Patients who changed opinion (n)
Fulfillment of expectations			
Relief of pain	0 0–0	1.0	0
Walking	0 -1–0	0.99	1
Stair-climbing	0 0–1	0.90	2
Social activities	0 0–0	1.0	0
Stability	0 0–1	0.90	1
Sleep	0 0–0	1.0	0
Straight leg	0 0–1	0.97	1
Questions			
Feeling of instability (N/Y)	0 0–1	0.90	1
Does your knee feel normal? (Y/A/N)	0 0–1	0.90	1

[a] Time between occasions 1 and 2: 1–2 weeks. Median difference and range
[b] Kendall's tau

various distributions between the two groups at 1 and 2 years felt incidental instability in any situation, including walking on uneven ground. At 1 year, 27 patients (14 F/13 C) felt that their knee was almost normal one, but none that it was completely normal. 1 year later, 17 (8/9) felt that it was almost and 6 (2/4) that it was normal. At the 2-year follow-up, the HSS scores reached 82 in the flat and 86 in the concave group (p = 0.2).

The median overall fulfillment of the expectations (almost or completely satisfied) was 68% (F: 0–100) in the flat and 86% (14–100) in the concave group (F vs. C: p = 0.2). The concave insert tended to be associated with a better fulfillment of the patients' expectations as regards stability after the operation (p = 0.04, Tables 4 and 5).

In the test of repeatability, there was a fairly good agreement between the answers given on the 2 occasions (Tables 1 and 6, Kendall's tau = 0.9–1.0).

Discussion

Andriacchi and Galante (1988) argued that the posterior cruciate ligament improves the range of passive motion, the mechanical efficiency of the knee musculature and consequently stair-climbing ability. Presence of this ligament was claimed to reduce stresses at the cement-bone-implant interfaces and have no effect on the polyethylene wear problems. On the other hand, Soudry et al. (1986) concluded that cruciate retention with low conformity of the tibial plateau gives higher contact forces, which may lead to more wear in the long term. Kadoya et al. (1998) stated that reduction in wear particles is of vital importance in dealing with the problem with osteolysis. This goal could be achieved by improving the materials in the prosthesis or the geometry of the articulating surfaces.

Small contact area is a problem with nonconforming tibial plateaus and especially if thin polyethylene is used in young and active patients (Wright et al. 1992, Bugbee et al. 1998). In a retrieval study of 280 uni- and bi/tricondylar knee arthroplasties, Blunn et al. (1997) concluded that delamination of the plastic caused the severest wear. In designs with relatively high conformity, this type of wear was associated with restriction of rotational movement of the femoral component or with abrupt changes in the radius of the tibial component. Wear attributed to cement abrasion or entrapment was also more commonly seen in the conforming designs. In less conforming designs (i.e., flatter), wear was associated with laxity, such that the polyethylene delaminated towards the edges of the tibial component. Designs of moderate conformity without abrupt changes in radii were regarded to be the most wear-resistant. On the basis of these findings and some assumptions, the concave insert in our study seems to be preferable, but longer follow-ups with more patients are probably necessary to substantiate these views.

Postak et al. (1992) compared the stability of 7 designs of TKR, each studied with 2 types of inserts, one with less and the other with more intrinsic mechanical stability. The flat insert in our study was one of three with the smallest resistance to anterior and medial displacements and axial rotations. The rotational stability of the concave AMK design was greater than that of the other 7 constrained designs studied, whereas the anteroposterior and medial-lateral stability were about the same magnitude or slightly less than those in similar designs (AP lipped, curved or ultra-congruent). Thus, according to these studies, the 2 types of inserts studied should be representative of implants with low or high intrinsic stability, respectively.

It should be stressed that these tests were done in full or close to full extension. During flexion, the radius of the part of the femoral component, which is in contact with the tibial surface, will decrease and the contact area will probably become smaller with both designs. In vivo, the artificial joint surfaces may not articulate with each other as originally intended by the designer of the implant, which makes this question more complex. In a previous study, we assessed the kinematics of the same TKA as in this study (Kärrholm et al. 1998). Unexpectedly, the constrained design showed more marked anteroposterior translations, suggesting that the views presented above about the tibiofemoral contact may not may be valid. With the constrained design, the anteroposterior displacements were sufficiently marked to, at least occasionally, indicate anterior dislocation of the femoral component out of the trough. The concave design may, in fact, not be so stable as could be expected, which could be one reason for the equal fixation found in the 2 groups.

Close conformity between the articulating surfaces may mean that forces caused by joint motion, not compatible with the design of the 2 surfaces, are transmitted to bone-cement interfaces. In the 2 designs studied, the net effect of the forces acting on the interfaces was probably about equal. Later on, both designs showed similar tendencies to increased axial rotation of the tibial insert, with increasing posterior slope of the component. During extension-flexion of the knee or twisting, the femoral condyles may have put pressure on the tibial joint surface and especially in an anterior direction. Without perfect matching of the components, the pressure in the anterior direction will become asymmetrically distributed between the 2 compartments. An increase in these forces with increasing posterior slope of the tibial component may explain the correlation between this position and the rotations around the longitudinal axis. The finding of increased rotation about the transverse axis in concave inserts with varus position suggests that there are indeed minor differences in the magnitude and direction of the forces transmitted to the interfaces between the 2 designs. If so, the clinical significance of these differences seems to be small—at least, in the short-term perspective.

Bourne et al. (1988) reported an improvement in the HSS scores from 57 before surgery to 86 5 years after posterior cruciate-retaining TKA. These authors stated that the results of posterior cruciate-sparing TKAs were excellent, with few complications. The slightly lower scores in our study can reflect a true difference. However, they could also be caused by the use of self-administered questionnaires, which gave the patients extra time to consider pain, function and expectations in their own homes and during 2 weeks before the visit to the outpatient clinic. Evaluation of HSS scores can also be expected to be observer-dependent. When the 2 observers in our study evaluated another patient group operated on with the Freeman-Samuelsson knee prosthesis, the mean HSS score dropped by 6 points, compared to a previous study of the same prosthesis, where the scoring was done by other observers (Regnér et al. 2000). Murray and Frost (1998) advocated questionnaires to evaluate the results of a total knee replacement. They pointed out that surgeons tend be overoptimistic about pain, which has a comparatively high effect on most scoring systems, not least that used in our study.

All patients had several expectations about their operation, most commonly improved walking and stair-climbing ability, relief of pain and better stability. The concave insert seemed to fulfill the patients' expectations about stability more adequately. When asked about stability, 8 (5 flat, 3 concave) of our patients considered that their operated knee was not stable in all situations. However, instability could not be confirmed by the clinical examination, perhaps because these tests did not reflect the stability during activity sufficiently well. In our previous study of knee kinematics (Uvehammer et al. 2000), we found a weak association between instability/sensation of abnormal knee and increased proximal displacement of the center of the tibial component at 50 degrees of flexion. This type of abnormality is probably very difficult to find on a clinical examination.

In our study, none of the patients regarded the knee function as normal 1 year postoperatively, but—interestingly—6 patients (2 flat, 4 concave) thought that the knee was functioning normally at the 2-year follow-up, although their HSS scores had hardly changed. This could represent a true change, but it may also be caused by adaptation.

Ryd et al. (1990) found a correlation between MTPM 1 and 4 years after the operation and the absolute deviation from the ideal 180-degree overall limb alignment (HKA). Correspondingly, the migration between 1 and 4 years was correlated to the PT-angle. In an earlier investigation by the same authors (Ryd et al. 1987) and in our study also, no such correlations were found. This discrepancy may indicate that small deviations from the ideal position in the frontal plane have a minor effect on prosthetic migration if adequate fixation techniques are used.

The AMK prosthesis with flat or concave inserts, with retention of the PCL, showed about the same migration as contemporary designs of TKAs (Ryd et al. 1987, 1990, Nilsson et al. 1999). We have previously documented increased anterior-posterior displacement of AMK prostheses with concave inserts. This abnormality seems to have no negative effect on migration or on clinical results. Our hypothesis that a comparatively flat joint area would result in less migration of the tibial component after total knee arthroplasty could not be confirmed. Moreover, the clinical outcome was similar in patients with flat or concave inserts.

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