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Ultra-Short Bone Conserving Cementless Femoral Stem

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Excellent long-term results have been reported with conventional length cementless femoral stems in total hip arthroplasty; however, proximal stress shielding and thigh pain are still a concern. Metaphyseal engaging bone conserving short stems provide theoretical benefits compared with conventional length cementless stems, including avoiding proximal-distal mismatch, decreasing proximal stress shielding, and limiting perioperative fractures. The purpose of the ultra-short bone conserving cementless stem was to reproduce natural load transfer with an ultra-short stem obtaining optimal stability using the morphology of the proximal femur. Loss of stability of the stem and failure of osseous ingrowth is a potential concern with the use of ultra-short proximal loading cementless femoral stems. Ultra-short, metaphyseal-fitting anatomic or non-anatomic cementless femoral stems provided stable fixation without relying on diaphyseal fixation in young and elderly patients, suggesting that metaphyseal-fitting alone is sufficient in young and elderly patients who have good bone quality.

Key Words: Ultra-short cementless stem, Total hip arthroplasty, Young and elderly patients

INTRODUCTION

Satisfactory clinical and radiographic outcomes at long-term follow-up may be achieved with use of conventional length cementless femoral stems (stem engaging metaphysis and diaphysis of the proximal femur)[1-7]. Despite excellent long-term results with most designs, stress-shielding and thigh pain may occur[4,5,8,9]. Several bone conserving femoral stems have been designed during the last two decades, including mid-short stem (engaging metaphysis and junction of the metaphysis and diaphysis of the proximal femur), and ultra-short stem (engaging only metaphysis of the proximal femur) and some authors have advocated their use, particularly in young patients with high activity interests[10,11]. The goals of bone conserving femoral stems include the following: sparing of the trochanteric bone stock; a more physiological loading in the proximal femur reducing the risk of stress shielding; and to avoid a long stem into the diaphysis preventing impingement with the femoral cortex and thigh pain[12,13]. Several systems for classification of bone conserving femoral stems have been developed, considering features such as length of the stem, location of loading, osteotomy level for the femoral neck resection and implant fixation principles (Table 1)[14-18].

McTighe et al.[14] proposed the term ‘short’ for stems that do not extend below the metaphyseal region of the proximal femur. In this respect, they proposed three types of stems: head stabilized (resurfacing); neck stabilized; and metaphyseal stabilized. Khanuja et al.[15] recently classified

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Table 1. Classification Systems for Femoral Stems

Study	Publication year	Classes	Description	Rationale
McTighe et al.[14]	2013	Resurfacing	Resurfacing	Assessment of length and method of achieving primary stability of the stem
		Neck stabilized	Short curved neck-sparing stems, and standard-length stems preserving femoral neck, but engaging the neck, metaphysis and diaphysis	
		Metaphyseal stabilized	Short metaphyseal stems including anatomical, straight and tapered designs	
		Conventional (metaphyseal/ diaphyseal) stabilized	Conventional stems engaging both metaphysis and diaphysis	
Feyen and Shimmin[17]	2014	Type I	Resurfacing	Assessment of the osteotomy level for the neck resection and implant fixation principles
		Type II	Mid-head resection stems	
		Type III	Short stems with subcapital (IIIA) or standard (IIIB) osteotomy	
		Type IV	Traditional stems	
		Type V	Diaphyseal fixation stems	
Van Oldenrijk et al.[18]	2014	Collum	Conical or cylindrical ultra-short stems, with complete anchorage in the femoral neck	Assessment of the osteotomy level for the neck resection and implant fixation principles
		Partial collum	Partial femoral neck-sparing curved designs	
		Trochanter-sparing	Trochanter-sparing but not neck-sparing, and shortened tapered stems	
Khanuja et al.[15]	2014	Type I	Femoral neck fixation stems (from IA to IC according to the stem geometry)	Assessment of location of loading and implant fixation principles
		Type II	Calcar loading stems (from IIA to IID according to the stem geometry)	
		Type III	Calcar loading with lateral flare stems	
		Type IV	Shortened tapered stems	
Falez et al.[16]	2015	Collum	Conical or cylindrical ultra-short stems, with complete anchorage in the femoral neck	Assessment of the osteotomy level for the neck resection and implant fixation principles
		Partial collum	Partial femoral neck-sparing curved designs	
		Trochanter-sparing	Trochanter-sparing but not neck-sparing, and shortened tapered stems	
		Trochanter-harming	Short stems interrupting the circumferential integrity of the femoral neck section and violating trochanteric region	

bone conserving short stems according to fixation principles and location of proximal loading. They proposed four categories: femoral neck fixation; calcar loading; lateral flare and calcar loading; and shortened taper stems. Similar prosthesis survival rates and functional outcomes in primary total hip arthroplasty (THA) were observed for the majority of bone conserving short femoral stems demonstrated, compared with conventional length cementless stems. However, superior bone remodeling and preservation of more proximal bone stock in the short and long-term may be achieved with a bone conserving short femoral stem. In addition, a bone conserving short femoral stem may be applied to any type of femoral morphology[10-28].

The purpose of this review was to focus exclusively on type III (classification by Feyen and Shimmin[17]) or type III (classification by Khanuja et al.[15]) bone conserving short femoral stems, providing a description of their features and an analysis of their clinical and radiological results, and survival rates.

ANATOMIC BASIS FOR BONE CONSERVING SHORT FEMORAL STEM

Dorr et al.[29] observed that the poor correlation between the proximal and distal dimensions of the femoral canal necessitates the selection of stems based on their fit in the proximal rather than the distal canal, thereby optimizing the metaphyseal load transfer. They also found that the mediolateral diameter of the femoral canal at a point 20 mm distal to the lesser trochanter has the most predictable relationship with external femoral dimensions. These findings provide an anatomical basis for the metaphyseal fixation of certain types of cementless stem.

BIOMECHANIC BASIS FOR BONE CONSERVING SHORT FEMORAL STEM

Walker et al.[30] suggested that extending the femoral stem beyond the lesser trochanter is unnecessary for a cementless anatomic femoral component with a lateral flare, and that a short, metaphyseal-fitting is sufficient. Leali et al.[21] found that a proximally fixed cementless femoral component with a lateral flare provided solid initial stability. When using a cementless stem, normal patterns of strain are approached when a tight proximal fit of the stem is achieved[31,32], whereas a tight distal fit can significantly reduce proximal strains[31]. The closer the contact of the distal part of the stem, the more proximal stress shielding occurs, whereas the absence of contact between the stem and the distal cortex may reduce stress shielding, bone resorption and thigh pain[31]. Hence the length of the stem plays is a critical component in the transfer of forces to the femoral bone. Conceptually, reducing the length of the stem reduces proximal stress shielding, at the cost of a reduced contact area for fixation and load transfer. Bieger et al.[33] and Arno et al.[34] suggested that shortening a femoral stem reduces proximal stress shielding without compromising primary stability. They also concluded that a metaphyseal only design biomechanically provides the best match of the native femur.

CLINICAL STUDIES ON BONE CONSERVING SHORT FEMORAL STEMS

1. IPS Stem (Lateral Flare Calcar Loading Anatomic Stem with Distal Stem)

Considering that most cementless femoral stems are applied in young patients, preservation of bone stock and reduction of thigh pain and osteolysis when possible would be advantageous. Conservative metaphyseal-fitting anatomic cementless femoral stems with an alternative bearing surface such as an alumina-on-alumina bearing meet this requirement. Metaphyseal-engaging short stems provide theoretical benefits compared with conventional length cementless stems, including avoiding proximal-distal mismatch, decreasing proximal stress shielding, and limiting perioperative fractures.

New total hip prosthesis (Immediate Postoperative Stability [IPS]; DePuy, Leeds, UK) was developed by Kim in 1995[35] (Fig. 1). The intention was to reproduce natural load transfer with a short stem while obtaining optimal stability using the morphology of the proximal femur. In this design of the stem, vertical stability was provided by the wedge shape of the prosthesis with the addition of a lateral flare. This increases the load on the proximal femur, medially and laterally, and decreases load transmission to the femoral diaphysis. The transition zone between the loadbearing and nonloadbearing section of the stem is short, avoiding metal-to bone contact below the metaphysis. The polished distal stem is short and narrow and placed centrally in the femoral canal to avoid distal contact with the femur. The proximal 30% of the stem is porous-coated with sintered titanium beads with a mean pore size of 250 μm to which a hydroxyapatite coating is applied to a thickness of 30 μm.

A summary of the clinical results on IPS short anatomic cementless stems is shown in Table 2[20,24,35-46]. Mild stress-shielding (calcar round-off) was observed and none of the patients experienced thigh pain. With an abundance of papers describing the use of IPS cementless stems with short follow-up, one paper reported long-term results (Table 2). The question of whether stable fixation can be obtained without diaphyseal fixation is a potential concern with the use of short, metaphyseal-fitting anatomic cementless femoral components. In our studies, osseointegration was reliable with an IPS stem[20,37-40]. Walker et al.[30] and Leali et al.[21] suggested that the femoral stem below the lesser trochanter would be unnecessary for a cementless anatomic femoral stem with a lateral flare and that a short stem would suffice.

2. Proxima Stem (Lateral Flare Calcar Loading Anatomic without Distal Stem)

A new ultra-short anatomic cementless femoral stem (Proxima; DePuy) was developed by Kim in 2001[23] (Fig. 2). One of the main reasons for developing a new ultra-short metaphyseal-fitting porous-coated anatomic cementless femoral stem was to preserve bone and to provide more physiological loading. The ultra-short Proxima cementless

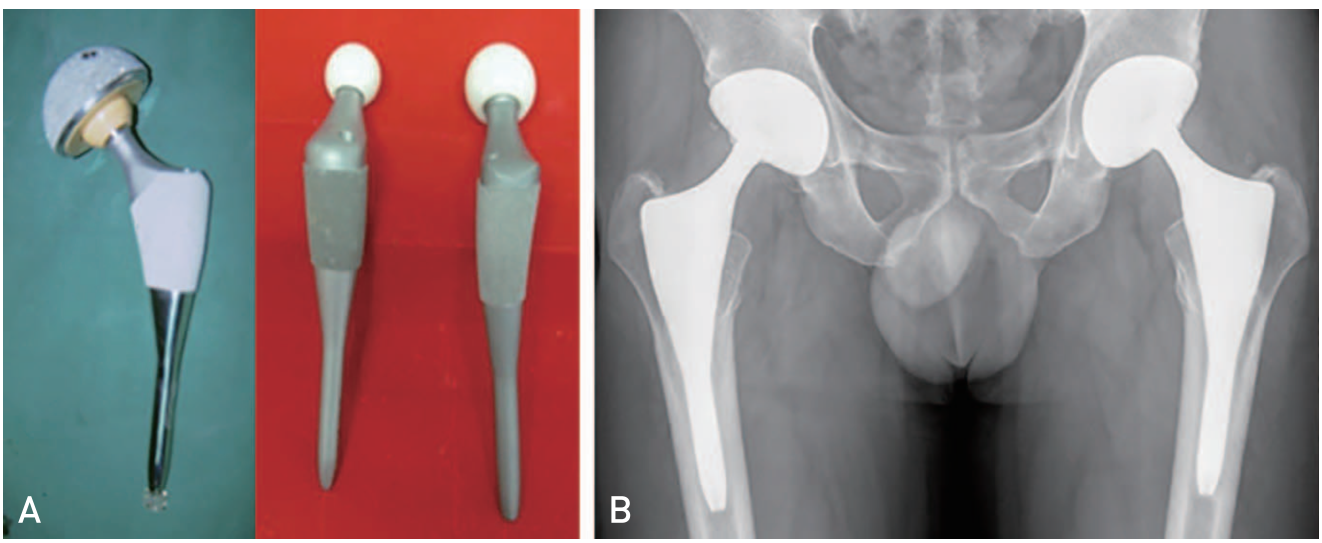

Fig. 1. (A, B) Photos of an IPS (Immediate Postoperative Stability; DePuy) stem and radiographs of both hips taken 20 years after the operation.

Table 2. Demographic Data and IPS Stem Survivorship

Study	Level of evidence	No. of hips	No. of patients	Mean age (yr)	Mean follow-up (yr)	Survivorship (%)
Kim et al.[37]	Level I	100	50	45.3	6.6	100
Kim et al.[38]	Level II	601	471	52.7	8.8	99.7
Kim et al.[20]	Level IV	630	500	52.7	15.8	100
Kim et al.[39]	Level I	140	120	45.3	6.4	100
Kim et al.[35]	Level III	60	50	46.6	6.3	100
Cinotti et al.[40]	Level IV	72	64	68	9	100
Kim et al.[41]	Level I	93	64	38.2	11.1	100
Kim et al.[42]	Level I	200	100	45.3	5.6	100
Kim et al.[43]	Level IV	73	71	45.5	8.5	100
Kim et al.[24]	Level IV	110	55	46.3	15.6	100
Kim et al.[44]	Level IV	127	96	24	14.6	100
Kim et al.[45]	Level IV	60	50	28.3	10.8	100
Kim et al.[46]	Level I	200	100	45.3	12.4	100
Kim et al.[36]	Level I	100	50	51	4.8	100

IPS: Immediate Postoperative Stability.

femoral stem is designed to have a close fit within the proximal femur with the aim of maximizing primary stability, particularly in torsion, thereby limiting bone resorption due to stress shielding. It is manufactured using titanium alloy and is entirely porous-coated with sintered titanium beads having a mean pore size of 250 μm, to which a 30 μm thick hydroxyapatite coating is applied, except for the distal tip. The design features include a longer proximomedial portion of the stem, a highly pronounced lateral flare and preservation of the femoral neck. The question arises, at the time of development, as to whether it is possible to obtain rigid fixation of this stem without diaphyseal anchoring.

A summary of the clinical results on Proxima ultra-short anatomic cementless stems is shown in Table 3[23-28,47-53]. Mild-stress shielding (calcar round-off) was observed and none of the patients experienced thigh pain. All of the previous studies[23-28,47-49] on Proxima stem suggested excellent clinical results in the short or long-term follow-up. Kim et al.[47] obtained similar long-term results using ultra-short and conventional length cementless anatomic femoral stems in patients <65 years old, in terms of clinical and radiographic results, survival rates, and complication rates. However, significantly higher incidence of thigh pain and stress shielding-related periprosthetic bone resorption was observed in the conventional length stem group compared with the ultra-short stem group.

It has been suggested that stress shielding may be minimized by a low-modulus, intimately fit proximally device

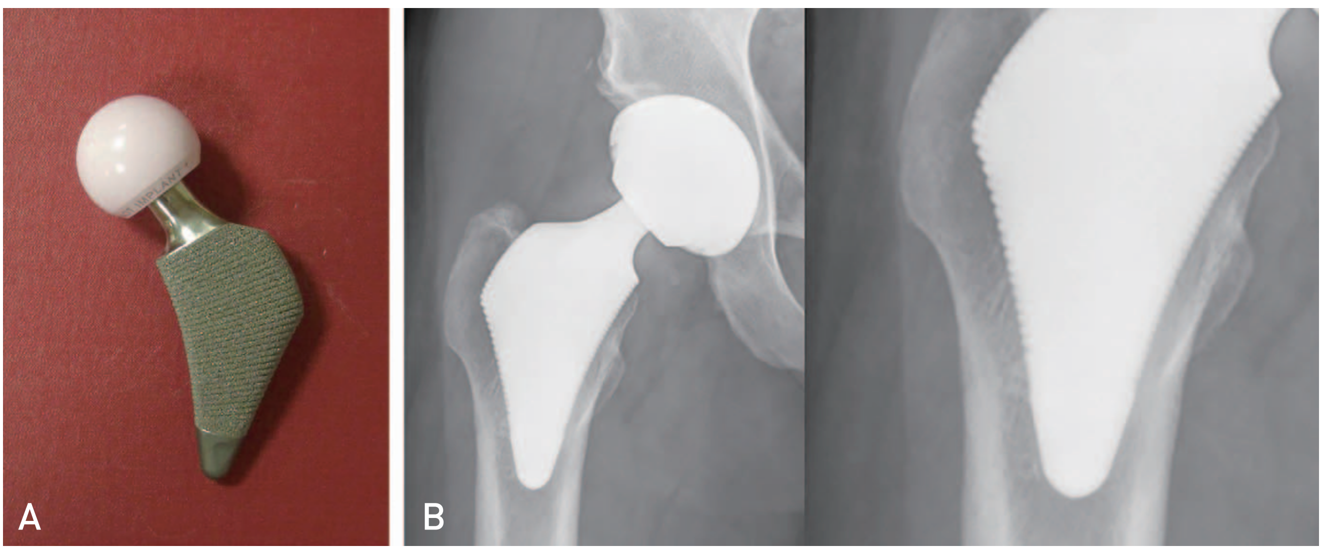

Fig. 2. (A, B) Photo of a Proxima (DePuy) stem and a radiograph of the right hip taken 15 years after the operation.

Table 3. Demographic Data and Proxima Stem Survivorship

Study	Level of evidence	No. of hips	No. of patients	Mean age (yr)	Mean follow-up (yr)	Survivorship (%)
Kim et al.[28]	Level IV	84	84	78.9	4.6	100
Kim et al.[27]	Level I	60	50	54.3	3.35	100
Kim et al.[26]	Level IV	144	126	53.9	4.5	100
Kim and Oh[25]	Level II	70	70	74.9	4.1	100
Kim et al.[24]	Level IV	256	230	65	5.5	98.2
Kim et al.[23]	Level IV	226	200	43.9/78.9	7.5	100
Kim et al.[47]	Level III	858	759	56.3	16.5	97.6
Renkawitz et al.[48]	Level IV	200	200	18-70	15	100
Rastogi and Marya[49]	Level IV	50	41	45	4	95.1
Kim et al.[50]	Level I	524	262	53	11.8	99.6
Gombár et al.[51]	Level IV	86	81	50	7	97
Melisík et al.[52]	Level IV	130	121	<60	9.8	98.5
Kim and Jang[53]	Level IV	284	280	72.8	9.3	97

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that does not bypass the proximal medial regions with distal fixation[20]. Using the ultra-short Proxima cementless anatomic femoral stem, a level of fixation in the proximal femur that was as adequate as that of the conventional length cementless anatomic femoral stem was achieved, but it provided significantly less stress shielding bone resorption than the conventional length cementless anatomic femoral stem[47].

It is believed that short-stemmed components are associated with a higher rate of coronal malalignment[15] when compared with femoral stems of conventional length. There was no significant difference in survivorship of varus components compared with neutrally implanted components. The findings of Kim et al.[50] concur with those of this systemic review (98.6% survivorship at 12 years).

The Australian Orthopaedic Association National Joint Replacement Registry[54] reported that the cumulative incidence of aseptic loosening for the short-stemmed THAs was more than twice that of other femoral components at 10 years (2.5% compared with 1.2%). In a long-term study, Kim et al.[50] found that the survival rate of the ultra-short cementless anatomic stem (97.6%) was comparable to that of the conventional length cementless anatomic stem (96.6%). They believed that the satisfactory results using the ultra-short cementless anatomic stem can be attributed to several factors, that is, good quality of bone, optimal preparation of the proximal femur along with preservation of the femoral neck, and circumferential metaphyseal fitting.

3. SMF Stem (Ultra-short Non-anatomic Calcar Loading Stem)

Among numerous short bone conserving proximal loading cementless stems, ultra-short anatomic and ultra-short non-anatomic proximal loading cementless femoral stems were introduced to facilitate osseointegration of the stem without diaphyseal stem fixation. In the ultra-short anatomic cementless stem (Proixma; DePuy) vertical stability is provided by the wedge shape of the stem with the addition of a lateral flare and preservation of the femoral neck. In the ultra-short non-anatomic proximal loading cementless stem (Short Modular Femoral [SMF]; Smith & Nephew, Memphis, TN, USA) (Fig. 3), vertical stability is provided by the wedge shape of the stem with 3-point fixation in the femoral canal and preservation of the femoral neck. Preservation of the femoral neck and the wedge shape of the stem provide greater torsional stability and reduce distal migration of the femoral stem. Absence of distal stem fixation is allowed because of the effective stability provided by the wedge shape of the stem with preservation of the femoral neck. The absence of diaphyseal stem fixation attempts proximal load transfer to reduce stress shielding and thigh pain. In addition, it attempts preservation of the femoral canal and femoral elasticity, and ease of revision. In the current study, mild stress shielding (calcar round-off) was observed and none of the patients experienced thigh pain.

McCalden et al.[55] conducted a randomized controlled trial comparing the patterns of migration of a SMF stem with

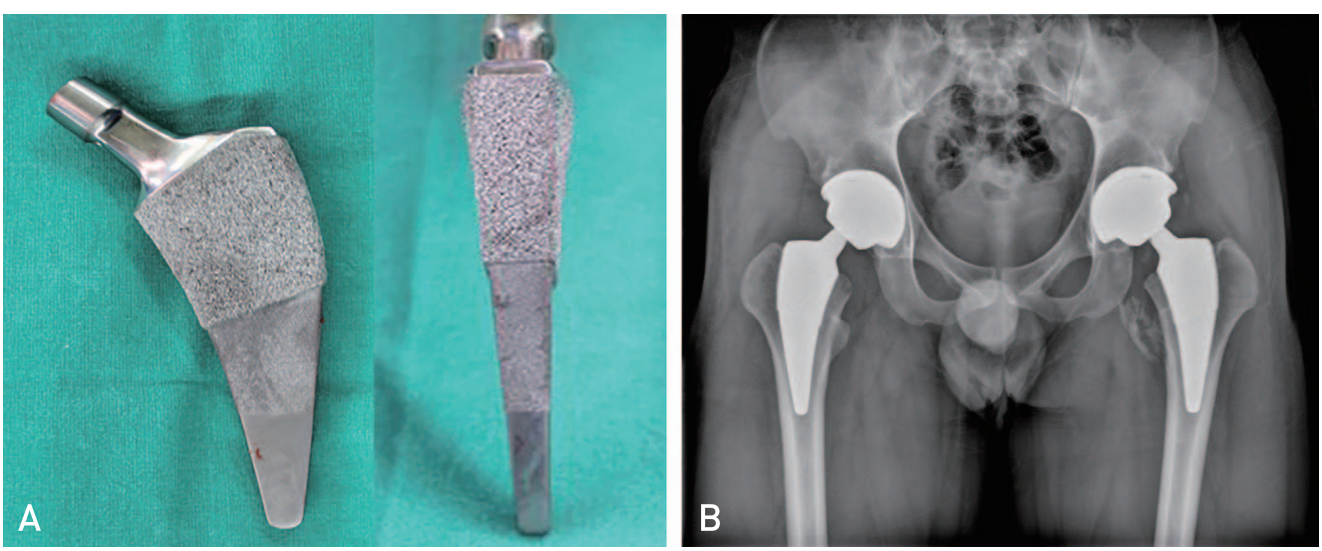

Fig. 3. (A, B) Photos of SMF (Short Modular Femoral; Smith & Nephew) stems and a radiograph of both hips taken seven years after the operation.

metaphyseal fixation in 22 patients with those of a conventional length femoral stem with metaphyseal fixation (Synergy; Smith & Nephew) in 21 patients. At 24 months after surgery, no statistically significant difference in mean migration was observed between the groups: total migration was 1.09±1.74 mm and 0.73±0.72 mm, respectively. A total migration <0.6 mm subsidence <0.5 mm and rotation <1.0° was observed for the majority of stems in both groups. In the group with SMF, early migration >1.0 mm which stabilized within six months was observed for three stems, and one stem had an early progressive migration requiring revision three years after surgery. In a study by Kim et al.[56], in the short-term (3.5 years) follow-up, rigid fixation of the stem occurred in all of the 56 hips with a SMF stem. The findings of McCalden et al.[55] and Kim et al.[56] support the assumption that torsional loads can be controlled without diaphyseal stem fixation by preservation of the neck and tight fixation in the metaphysis of the femur.

CONCLUSION

Loss of stability of the stem and failure of osseous ingrowths are potential concerns with the use of an ultra-short proximal loading cementless femoral stem. However, ultra-short, metaphyseal-fitting anatomic or non-anatomic cementless femoral stems provided stable fixation without relying on diaphyseal fixation in young and elderly patients, suggesting that metaphyseal-fitting alone is sufficient in young and elderly patients who have good bone quality.

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CONFLICT OF INTEREST

The authors declare that there is no potential conflict of interest relevant to this article.

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