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Maintenance of graft compression in the adult cervical spine

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Abstract It is generally advised that the graft inserted in adult cervical spine should be pre-loaded with a compressive force or that the screws are inserted in a divergent orientation, in order to maximise compression and the chance of graft incorporation (Truumees et al. in *Spine* 28:1097–1102, 2003). However, there is little evidence that a compressive force is maintained once the force applicator has been removed, or that the divergent screws enhance compression. This study compared the maintenance of applied pre-load force, across cervical spine graft, between standard anterior plating technique with pre-load and divergent screws and a novel plate technique, which allows its application prior to removal of the force applicator. Six intact adult cadaveric human cervical spines were exposed by standard surgical technique. A Casper type distracter was inserted across the disc space of interest, the disc was removed. In 14 experiments, following the disc removal, an autologous iliac crest bone graft was inserted under distraction, together with a strain gauge pressure transducer. A resting output from the transducer was recorded. The voltage output has a linear relationship with compressive force. A standardised compressive force was applied across the graft through the “Casper type” distracter/compressor (7.5 kg, torque). The

pre-load compressive force was measured using a torque drill. Then two different procedures were used in order to compare the final applied strain on the bone graft. In eight experiments (procedure 1), the “Casper type” distracter/compressor was removed and a standard anterior cervical plate with four divergent screws was inserted. In six experiments (procedure 2), a novel plate design was inserted prior to removal of the distracter/compressor, which is not possible with the standard plate design. A final compressive force across the graft was measured. For the standard plate construct (procedure 1), the applied compression force is significantly greater than resting (SO/SC)— $P=0.01$, but the compression force is not maintained once the compressor is removed (SO/SR)— $P=0.27$. Final bone graft compression after plate insertion is not significantly different to the resting state (SO/SF)— $P=0.16$ (Wilcoxon’s sign test for paired observation). Application of the plate tended to offload the graft; the final compressive force is $170 \pm 100\%$ less than the resting force. None of the applied force was maintained (mean $9.5 \pm 8.8\%$). For the new plate (procedure 2), the end compressive force (SF) measured across the graft was greater than the resting force (SO) ($P<0.001$). Further, the novel plate application

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increased the compressive force on the graft by $712 \pm 484\%$. The final bone graft compression using a novel plate, which allows its application prior to removal of the force applicator, is significant (SO/SF)— $P=0.01$. Here, $77 \pm 10\%$ of the applied pre-load was maintained. The difference between the plates is significant ($P<0.001$). Conclusions are as follows: (1) Applied pre-load is not maintained across a graft once

the force applicator is removed. (2) Divergent screws with a plate do not compress graft and rather tend to offload it. (3) Compressive force may be maintained if the plate is applied prior to the force applicator removal.

Keywords Cervical spine · Bone graft · Graft compression · Standard cervical plate system · Novel plate

Introduction

Anterior cervical discectomy and fusion is one of the most commonly performed procedures for cervical spine degenerative disc disease, since it was described originally by Robinson and Smith [1] and Cloward [2]. Complications with these procedures such as graft extrusion, graft collapse, end plate fracture and pseudoarthrosis are not uncommon [3–5]. In order to avoid these problems, some authors recommend the use of anterior cervical locking plate mechanism for single- and multi-level anterior cervical surgery [6–10].

Over the past several years, various biomechanical studies have been performed for the evaluation of instrumentation in assessing stability of the cervical spine [7, 11, 12]. Wang et al. [13] in a biomechanical study compared the loading characteristics of the bone graft–endplate interface for standard tri-cortical grafts and reverse tri-cortical grafts as a function of cervical positioning. In a separate study, Wang [14] investigated the role of bone graft force in enhancing stability of multilevel anterior cervical spine plate system. Truumees et al. [15] demonstrated the use of dynamic cervical compression plate to increase compressive load on interbody grafts in a multilevel anterior cervical discectomy model.

It is generally advised that the graft inserted in adult cervical spine should be pre-loaded with a compressive force in order to maximise the chance of graft incorporation and to prevent its extrusion and collapse [15]. It is further advised that the divergent screws should be used to maximise the graft compression. However, it has not been demonstrated that an applied pre-load is maintained once a plate is inserted whether or not divergent screw is used. None of the studies have investigated the application of an anterior cervical plate before removal of the force applicator, which in theory would allow maintenance of the applied pre-load compressive force. The purpose of this study is to investigate if the applied pre-load is maintained across cervical graft and to compare the maintenance of applied pre-load force be-

tween standard anterior plating technique and a novel plate technique, which allows an application of the plate prior to removal of the force applicator which is not possible with the standard plate design.

Methods

Strain gauge

A general purpose Constantan grid that is supplied fully encapsulated, and with exposed copper-coated integral solder tabs (CEA-06-125UN, Vishay Micro-Measurements Inc., Raleigh, NC) was used. Its main characteristics are as follows: its size is $9 \times 5 \text{ mm}^2$, a nominal resistance of $350 \pm 0/3\%$ and a gauge factor at 240°C of $2.085 \pm 0.5\%$.

In order to minimise the size of the transducer, this strain gauge is mounted on a thin aluminium plate ($20 \times 7 \times 1 \text{ mm}^3$).

The strain gauge is connected using low-resistance cables to a strain indicator (p-3500, Vishay Micro-Measurements Inc., Raleigh, NC) to a Wheatstone bridge circuit. To perform the measurements, the one-fourth bridge mode was used.

Clinical procedure

Six intact adult cadaveric human cervical spines were exposed by standard surgical technique. On two cadavers levels C3/4, C5/6 and C7/T1 were operated on and C4/5 and C6/7 in the remaining four cadavers. A Casper type distracter was inserted across the disc space of interest, and the disc was removed.

In 14 experiments, following the disc removal, an autologous iliac crest bone graft was inserted under distraction, together with a strain gauge pressure transducer, as shown in Fig. 1. The bone graft was uniform with a standard cutting fresh graft for each level to ensure proper graft size. A resting output from the

Fig. 1 The transducer and the bone graft inserted between cervical vertebrae

Transducer

transducer was recorded (noted S0). The voltage output has a linear relationship with compressive force.

Then two different procedures were used in order to compare the final applied strain on the bone graft. The first procedure is considered as a standard technique and the second is a novel technique made possible by its design:

For both the procedures, a standardised compressive force (7.5 kg, torque) was applied across the graft through the “Casper type” distractor/compressor, and the pre-load compressive force was measured using a torque drill (noted SC). For each experiment, the pressure was measured once to avoid screw loosening with repeated application and removal of force.

In eight experiments (procedure #1), the “Casper type” distractor/compressor was removed and a stan-

dard cervical plate with four divergent screws was inserted. A final compressive force was measured (noted SF).

In six experiments (procedure #2), a novel plate design was inserted prior to removal of the distractor/compressor. This design of the plate allows insertion of the plate while the compressor/distractor remains in place, thus maintaining the compression across the construct which is not possible with the standard plate design. A final compressive force across the graft was measured (noted SF).

Design of the novel plate

The novel plate has two notches where the screws would be inserted. Figure 2 illustrates the instillation principle of the novel plate design. The novel plate is secured into a place by inserting the notches which slide into the distractor/compressor pins. As highlighted, the bone graft compression is maintained with the distractor/compressor, while inserting and applying screws in the novel plate. In addition, a spring locking system is applied onto the plate to prevent an extrusion of the screws.

In contrast all other plates (without notches), can only be applied after the distractor/compressor has been removed.

Fig. 2 Instillation principle of the novel plate. The plate is inserted over the “Casper” type pins, maintaining compression

Results

Procedure #1

The results of the procedure #1 are shown in Fig. 3. The applied compression force is significantly greater than resting (S0/SC) $P < 0.01$. Compression force is not maintained once the compressor is removed

Fig. 3 The recorded bridge circuit potential at different states for procedure #1. S0 resting, SC following compression, etc.

(S0/SR)— $P=0.27$. Final bone graft compression after plate insertion is not significant (S0/SF)— $P=0.16$. Application of the plate tended to offload the graft, the final compressive force is $170 \pm 100\%$ less than the compressed force. None of the applied force was maintained (mean $9.5 \pm 8.8\%$).

Procedure #2

With the novel plate design, the results are shown in Fig. 4. The end compressive force (SF) measured across the graft was greater than the resting force (S0) ($P<0.001$). Further, the novel plate application increased the compressive force on the graft by $712 \pm 484\%$. The final bone graft compression using a novel plate, which allows its application prior to removal of the force applicator, is significant (S0/SF) $P<0.01$. Figure 4 shows the final construct. With the novel plate technique, the bone graft compression is maintained after the final construct.

Fig. 4 The recorded bridge circuit potential at different states for procedure #2. S0 resting force, SC following compression force and SF end compression force

Comparative results

Figure 5 and 6 compare the final bone graft compression for the standard technique and for the novel plate technique.

With the standard plate technique the end compressive force, following plate insertion is never maintained. None of the applied force was maintained (mean $9.5 \pm 8.8\%$).

The novel plate technique allows us to maintain an average of $77 \pm 10\%$ of the bone graft compression, as applied by a compression instrument at will.

The difference between the plates is significant ($P<0.001$).

Discussion

In the early part of the twentieth century, cervical spine surgery was primarily performed from the posterior approach. The anterior approach to the cervical spine has proved to be an extremely important surgical innovation, and when applied to cervical spondylosis and its neurologic sequelae, anterior cervical discectomy techniques are the standard procedures of choice in the management of cervical radiculopathy or cervical myelopathy [16]. Historically, Cloward [2] and Robinson and Smith [1] described anterior cervical discectomy and fusion procedures in mid-1950s, and since then these have become widely accepted in the treatment for cervical spondylosis and disc disease.

Anterior cervical fixation, using cervical plates and screws first introduced in 1989 by Casper [6], when he published a series of 260 anterior cervical plate fusions for trauma, came into practice with the aim to provide the stability of the construct (anterior strut graft, plate and screws) while natural bony fusion occurs [8–10].

Fig. 5 The final bone graft compression is maintained with the novel plate design

Fig. 6 Final construct with the novel plate design, with strain gauge in situ

Wolf's Law [17] states that the rate of bony fusion increases when the compression is maintained across the graft. However, concerns have been expressed that the anterior plate application may offload the graft or lead to stress shielding, interfering with fusion.

This has led to the recommendations that grafts should be pre-loaded prior to the plate insertion or that the plates should be inserted using a divergent screw direction in order that screw tightening will compress the graft.

There is no evidence to support such recommendations.

Our study is based on the hypothesis that an anterior cervical plate should be inserted before the removal of force applicator in order to maintain any applied pre-load force.

Previous studies [14] have clearly demonstrated pre-load across the bone graft that plays an important role in the stability of the plate construct. There are other variables which define the final stability such as size of the graft and degree of distractive force required to insert the graft [18]. However, there is no indication that the applied preload is maintained when the distracter/compressor is removed in order to apply the anterior cervical plate. To our knowledge, there are no published studies that have looked at maintenance of the pre-load compressive force after the application of the anterior cervical plate as the present design of the standard plating system does not permit this variable to be measured. The advantage of the novel technique is that it allows the plate to be inserted with the distracter/compressor pins in situ.

In the present study, a strain gauge transducer was inserted between the bone graft and the vertebrae. One possible drawback of this method is that it is difficult to get an absolute strain value when standardising between

cadavers or levels in terms of graft and bone quality, in such a geometric environment, however, using comparative values, we have clearly distinguished between the two plating systems. Further the transducer is fragile. The major advantage, however, is that the transducer thickness is very small allowing an insertion between the bone graft and the vertebrae.

In the current study, the results of the first procedure demonstrated that the compressive force from the compression was significantly different to resting ($P=0.01$) but the compressor force was not maintained after the removal of the compressor ($P=0.27$) and the final bone graft compression after the plate insertion was not significantly different to resting ($P=0.16$), indeed the plate tended to offload the graft.

With the use of the novel plate, the end compressive force was greater than the resting force. The bone graft compression was maintained through the final construct ($P<0.01$).

The comparative results of the final bone graft compression for the standard technique and for the novel plate technique were impressive. With the standard plate technique the end compressive force, following the plate insertion was never maintained. None of the applied force was maintained (mean $9.5 \pm 8.8\%$). In contrast, the novel plate technique maintained an average $77 \pm 10\%$ of the bone graft compression, as applied by the compression instrument. The difference between the plates was significant ($P<0.001$). Even though in this study we only looked at the compression force on autologous bone graft, we would expect that the comparative results would hold true for any particular graft type used.

This experiment did not look specifically at segmental or adjacent level lordosis, but if the graft is fitted in distraction and the compressive force is only applied onto a stable well fitted graft there should in theory be no difference between this novel plate and other anterior cervical plating systems. Standard plate technique has limitation in graft load share [16]. In theory this novel plate design may provide a clinical benefit in terms of pseudoarthrosis rate, graft extrusion or use in osteoporosis, however, this remains unproven and future studies should be encouraged to look at these potential benefits.

Conclusions

The current study demonstrates that the applied pre-load force is not maintained with standard anterior cervical plate design. In addition, the insertion of divergent screws does not lead to significant graft compression. The results clearly demonstrate that a novel plate design allows significant compression of the anterior cervical graft and maintenance of applied pre-load

forces when compared to standard techniques. Based on these findings, we suggest a prospective comparative study to evaluate the long-term results between the standard plating techniques and the novel plate.

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